The health of Auckland’s natural & constructed urban wetlands

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1.Abstract

I analysed data from 31 Auckland urban wetland monitoring plots within the Auckland metropolitan urban area. These plots were initially established from 2010 – 2014 by the Auckland council as part of a wider program to provide representative, region-wide monitoring of wetland health and biodiversity values. Data comprised two measures: the first baseline measurement and the 1st re-measurement after 5 years. It is planned to continue measuring these plots every five years, but only two measures were available for analysis in this study. The plots were selected using a 4km x 4km 'wetland grid' superimposed across the Auckland region to ensure representative spatial coverage. Each plot used a smaller grid setup of a square 15m x15m plot in which a 10m x 10m square and nine 2m x 2m plots were established within. This study aimed to assess the 'health' of Auckland's urban wetlands using this data through the calculation and analysis of multiple indicators of 'environmental condition'. These indicators were also evaluated through their usefulness towards the overall assessment of ecosystem 'health'. The first indicator was the analysis of plant species richness in the plot. Indicator 2 was 'naturalness' which compares native vs exotic plant species richness. The third indicator was naturalness (biomass) which provided more information on the growth and proliferation of native plant species in the plots. Indicator 4 was based on the Shannon Diversity index which incorporates aspects of species richness and the relative abundance of those same species (using biomass). Indicator 5 represented Weed Dominance, in which the level of weedy plant species biomass was evaluated over the plot to determine the plots resistance to invasions. Indicator 6 was the proportions of dryland plants, which shows the proportionate value of Dryland plant biomass across the whole plot in order to ascertain the level of 'drying out' or changes in hydrological regimes. Indicator 7 was based on the Dieback of plant species, where dead biomass of native and exotic plant species is measured over the total biomass and expressed as a proportion. Prior to analysis, the wetland plots were classed into four different wetland types, Coastal wetlands – Induced, Coastal wetlands -Natural, Freshwater wetland -Natural and Freshwater – Restored. Using statistical tests, no significance differences were found between the baseline measures and 5-year re-measurement across all the indicators. However, there were some significant differences between wetland types in indicators 1, 3 and 4. The lack of significance may be due to the low amount of datapoints as the lack of a 2nd re-measurement would have provided more data over a longer period (of 10 years). At Kohuora Park, four replicate plots were re- measured after 9-years as to compare indicator values and predict the change in 'health' of Auckland urban wetland plots after a 9-year period. However, due to the low sample size, no significant differences were detected.

Attestation of Authorship

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of learning."

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Introduction

Wetland Background

Wetland is a term used to describe areas that have been characterized by their hydrology, unique soils and plants that rely upon the specific wet conditions provided by the wetland (MfE – DOC 2007). Wetlands provide a vital ecosystem service for human societies and the wider environment, including a range of biodiversity, cultural and economic benefits.

A wide variety of different types of wetlands have been recognised in Aotearoa-New Zealand (Johnson & Gerbeaux, 2004). Included within the wider 'wetland' classification are a broad range of 'wet' ecosystems such swamps, estuaries, marshes, mires, swamp forest, pakihi, gumland, fens, and bogs. Unfortunately, wetlands are amongst the most threatened terrestrial ecosystems, both internationally (Xu, et al., 2019; Davidson, 2014) and in New Zealand (Ausseil, et al., 2008). Threats such as urbanization, habitat loss and climate change have affected the sustainability of wetland ecosystems around the globe as lands are cleared, drained, and burned for urban development, resource collection or damaged by the raising temperature or changed hydrology (Salimi, Almuktar, & Scholz, 2021). The overall proportion of freshwater wetland loss is probably around 90% for Aotearoa - NZ as a whole (Ausseil, et al., 2008), although this does vary from place-to-place. For example, in Auckland Region ecological districts the proportion of freshwater wetland (including swamp forest) loss varies from c.50% in Waitakere Ecological District to >99% in Manukau Ecological District (Lindsay, Wild, & Byers, 2009). The Auckland isthmus – which is the area of focus for this dissertation – has lost more than 99.6% of its natural freshwater ecosystems over the last 160 years (Auckland Council unpublished data)

Wetland loss in New Zealand is mainly due to urbanization & expansion of agriculture. Most of Aotearoa's major cities were constructed on wetland locations to make use of the flat, fertile farmland that drained wetlands provided, leading to a cascading effect as further wetland areas were reclaimed as to support the population growth and needs (Peters, et al., 2010).

While wetland clearance has slowed in recent decades, it is still ongoing. Around 5400ha of freshwater wetland vegetation, and 60ha of saline wetlands were lost between 1996 to 2018 due to non-natural threats (Denyer, 2020). New Zealand has developed a range of different policies, rules and laws to regulate (i.e., reduce) the clearance of wetland habitats and provide protection for those that remain. For example, the Resource Management Act (RMA 1991), which was created to streamline the approach towards environmental management while acting as a tool towards coordination and understanding.

The RMA acts as a guide towards the development of restoration and monitoring projects, which is tasked to the various regional councils and unitary authorities. The importance of preserving, enhancing and restoring wetlands has been specifically identified as priority for sustainable land management (MfE, 2019; MtE, 2020). Regional council and unitary authorities are tasked with protecting wetlands from inappropriate use and development alongside enhancement and maintenance of water bodied ecosystems and water quality, thus creating various restoration programmes over the years. As these projects are underway, monitoring projects becomes vital as to keep track of the progress of these restoration models as well as providing adaptive management to new threats and challenges (LoSchiavo, et al., 2013) This allows for further insight towards the goals of the projects while contributing towards data collection and accumulating additional information of the monitored ecosystem.

Constructed wetlands

Wetland ecosystems include artificial and constructed wetlands (called 'restored wetlands' in this dissertation). Many countries have developed relatively large-scale ecosystem restoration programmes to help reduce the rate of biodiversity loss while restoring and preserving the threatened ecosystems (Nias, Alexander, & Herring, 2003; Zhang, et al., 2020; Worrall, Perberdy, & Millett, 1997).

Constructed wetlands are artificially created wetlands, mostly established with the goal of enhancing, restoring, or constructing wetlands ecosystems. Their design, creation and application produce ecosystem services, mainly functioning towards wastewater and stormwater management (Biswal & Balasubramanian, 2022; Elzein, Abdou, & ElGawad, 2016). This is accomplished by three different types of constructed wetlands which are specifically designed towards mimicking key features of the natural wetlands, such as the filtration of chemicals, sediment retention, integrated nutrient cycle, predation, and pollutant processing (Maiga, Sperling, & Mihelcic, 2017). Furthermore, their construction and maintenance are relatively low cost and effort which is due to their design. The artificial mimicking of the key features occurs within the water flow of the constructed wetlands as it uses the interaction with the biota via manipulation of the hydraulic and hydraulic conditions of the wetlands. This is accomplished by the selection and the establishment of native key plant species alongside other supplemented plant species. Each key species are specifically chosen due to their current disposition as wetland plants, strong pollutant removal and tolerance, and low weed risk to the surrounding region (Tanner, Champion, & Kloosterman, 2006). Furthermore, the selection of these plants are dependent on the specific pollutants or chemicals that the constructed wetland aims to treat. Each key plant species has different levels of tolerance, pollutant processing and detention times in their respective systems. The level of water depth is also a factor as different water depth areas affect the establishment and propagation of implemented plant species, such as the shallow depths which require plants that are able to establish itself and reproduce under the conditions where the water depth is less than one meter (Cunningham, et al., 2017).

These three types of constructed wetland designs are known as surface-flow wetland (SFW), subsurface flow wetland (SSFW) and floating treatment wetland (FTW). Each of these types of constructed wetlands are used in different circumstances, depending on the required level of wastewater management needed.

These constructed wetlands are used in conjunction with other forms of wetlands within the Auckland isthmus such as the palustrine wetlands as well as open water wetlands.

Ecosystem services provided by constructed wetlands

Wetlands provide many services to the ecosystem, naturally or constructed. These services vary from water filtration, flood management, and carbon cycle contributions. However, the main purpose of constructed wetlands is towards filtration and improvement of water quality (Bai, et al., 2020), in which the unique layout of wetlands providing a terrestrial element alongside either freshwater or saltwater water flow allows this to occur. This is due to the water flow and interaction with the wetland vegetation that allows for removal of pollutants within the water or sediment, which is known as the biota and the hydrological regime. The extend of filtration provided by the wetlands also extend to pollution removal in three different processes, nutrient removal, sediment trapping and chemical detoxification (Luederitz, Eckert, Lange-Weber, Lange, & Gersberg, 2001; Khan, Nawab, & Waqas, 2020).

The filtration process is removal of excess nutrients such as nitrates and phosphorus which is a runoff from fertilizer or farm wastewater. Nitrogen removal is accomplished by the denitrification of nitrogen by heterotrophic bacteria. This is important as due to its heterotrophic nature of the bacteria, a reliable source of carbon is required and is provided by the wetland biota, converting the nitrate into nitrogen, which is released back into the atmosphere (Batanero, et al., 2022). This is further enhanced by the anaerobic nature of wetland soils as due the inclusion of water, causes the soil to be anoxic which is an ideal condition for the bacteria and denitrification process (Cleemput, Boeckx, Lindgren, & Tonderski, 2007). For the phosphorus however, the sequestration process is more long term as the phosphorus are usually attached to sedimentary particles such as soils or in the form of particulates. The removal of phosphorous from the sediment usually includes the assistance of the wetland biota which slow down the water flow and impedes on the travel of the particulates, which slows down and eventually settles upon the surface level of the soil sediment. The phosphorus is then slowly buried by decomposing plant matter such as roots, leaves, or stems and other decomposing matter (Vymaxal, 2007). This process constantly buries phosphorus within the soil content and alongside the constant inclusion of degrading plant matter, create the soil form known as peat.

Sediment trapping share the same process with the phosphorus as toxic chemicals within the wastewater runoff is trapped within the sediment soil particulates. This is further assisted by the other process of chemical detoxification as some of these pollutants are broken down by biological process/ decomposition from bacteria while pathogens are broken down from long exposure to ultra-violet radiation within open water areas (Ghermandi, Bixio, & Thoeye, 2007).

Biodiversity monitoring

Biodiversity is a composite term used to embrace the variety of types, forms, spatial arrangements, processes, and interactions of biological systems at all scales and levels of organization (Noss, 1990). It is widely accepted that many components of biodiversity are being lost rapidly at global scales, with significant impacts on the well-being of both natural systems and human societies (World Resources Institute, 2005; Peterson & Soberon, 2009). Primary causes of the current biodiversity crisis are the destruction, fragmentation, and deterioration of ecosystems, invasive species, pollution, overharvesting, and increasingly, climate change (Groom, Meffe, & Carrol, 2006). The resulting decline in ecological integrity warrants concern (Tilman, Wedin, & Knops, 1996; Stachowicz, Whitlatch, & Osman, 1999; Diaz, Fargione, Chaplin III, & Tillman, 2006; Valiente- Banuet, et al., 2015). In addition to its intrinsic value, indigenous biodiversity is essential to the provision of ecosystem services such as climate regulation, biofiltration of water, erosion control and sediment retention, pollination, recreation, and resource use (Costanza, et al., 1997; McAlpine & Wotton, 2009).

Increasingly, land management agencies are developing regional and national monitoring programmes to more closely inventory, monitor, and report on biodiversity (Lane & McDonald, 2002; Manley, Zielinski, Schlesinger, & Mori, 2004). The quality of Auckland's natural environment is consistently ranked by Aucklanders as an integral part of their quality of life and what is great about the Auckland region (Auckland Council 2011, 2014).

Typically, biodiversity monitoring programmes make use of suitable indicators. These indicators reflect the effect of environmental change on ecosystems and are indicative of the diversity of a subset of taxa or of the whole diversity within an area (McGeogh, 1998; McGeoch & Chown, 1998). 'Useful' biodiversity indicators have several key features(Manley, Zielinski, Schlesinger, & Mori, 2004; Wilcove, 1993):

1. They quantify information so that its significance is more apparent.

2. They simplify information about complex phenomena.

3. They are a cost-effective alternative to monitoring many individual processes or species.

4. Indicator frameworks use multiple indicators that measure different aspects of environmental health and therefore are not necessarily highly correlated

Ideally, the indicators used in a monitoring programme should operate across the spectrum of the ecological hierarchy, i.e., indicators at the level of species, populations, communities, habitats, ecosystems and landscapes (Noss, 1990). While indicators are considered necessary, the assumption that the status of a few species and ecosystem parameters can indicate ecological integrity has been widely challenged (Niemi, Hanowski, Lima, Nicholls, & Weiland, 1997; Lindenmayer & Likens, 2010; Niemi & McDonald, Application of Ecological Indicators, 2004).

In Auckland, the council mainly uses the Terrestrial Biodiversity Monitoring Programme (TBMP) and its extension, Wetland Monitoring Programme (WMP) to monitor indigenous biodiversity at the landscape scale. Data from wetland plots established as part of the WMP are the primary information source for the analyses presented in this dissertation. Specifically, I analyse data from two measures of Auckland Council wetland plots that lie within Auckland Metropolitan Urban Limits – called urban wetlands in this study. The data was collected on a five-year rotation and use the data from the baseline (2010 -2014) and 1st re-measurement (2015-2019) of these plots. Unfortunately, we were only able to access data for the two measurements in each plot. This is a severe dearth of long-term monitoring data for all indigenous ecosystems in New Zealand.

Auckland wetland monitoring program

In the 2009/10 field season the former Auckland Regional Council (ARC) commenced fieldwork on the first ever program designed to provide representative, region-wide monitoring of forest (2019) and wetland (starting 2010) biodiversity across the Auckland region; the Terrestrial Biodiversity Monitoring Program (TBMP). On the 1 November 2010 the ARC was dissolved into the new Auckland Council unitary authority, and the Research Investigation & Monitoring Unit (RIMU) of Auckland Council took over responsibility for the TBMP.

The WMP is based around five-yearly vegetation, bird and wetland condition monitoring of approximately 180 wetlands throughout the Auckland Region, including the Hauraki Gulf islands. The wetlands which receive regular monitoring were selected using a 4km x 4km grid to ensure good spatial coverage. The scale of these programmes allowed for the measurement of changes within the native biodiversity of the wetlands alongside examining the distribution of weeds and pests. The significance of the data collected by the WMP is vital towards assessing the progression of implemented policies and conservation plans as it allows analyzation of the sustainability and visibility towards if goals are being met. The data accrued is also quite diverse, allowing for wider interpretation in conjunction with other monitoring programmes.

Auckland wetlands

Current stocks of wetland assets in the Auckland Region are reflective of the region's landforms and development history. The region has c. 490,000 ha of land area and is relatively varied in terms of topography and geology, encompassing parts of 13 ecological districts and four ecological regions (McEwen, 1987). Almost 90% of the region's land area is < 8 km from the coast, there are few large rivers, and only two natural lakes > 50 ha in size. However, the regions long and sinuous coastline, many harbours and estuaries and collection of offshore islands mean it is relatively rich in brackish and saline wetland systems.

Freshwater wetlands are critically threatened in the Auckland Region, with less than 4% of the original extent remaining and only 38% protected (Lindsay, Wild, & Byers, 2009).

The most recent regional wetland survey was based on 2011 aerial imagery and is reported in (Lawrence & Bishop, 2017). More than 11,500 wetland polygons were mapped across the Auckland region with a total area of approximately 17,250ha. Most wetlands mapped were small and/ or modified wetlands that had not been accounted for in previous wetland surveys, which had focused on wetlands with higher biodiversity and ecological values. Estuarine and palustrine wetland are the two most extensive hydro systems in the Auckland region making up 65 per cent and 22 per cent respectively of all current wetland area. Riverine and lacustrine wetlands are the rarest form of wetlands.

Auckland urban wetlands

Urban wetlands are simply wetlands (natural or recreated) located within an urban setting. Most urban wetlands do not survive the urbanisation process. The Auckland isthmus in particular has seen a precipitous decline in the quantity and quality of its wetland ecosystems as wetlands were drained and cleared to provide more land for development. Ferdinand von Hochstetter's 1859 geological map of the Auckland Isthmus identified more than 815 ha of freshwater wetland of which only c. 3 ha (c. 0.4%) remained in 2010 (Auckland Council unpublished data). Urban wetlands often include a relatively large proportion of constructed or restored wetlands. These are used within the Auckland isthmus to enhance native wetland remnants and provide ecosystem services.

Wetland clearance is ongoing. Auckland lost 58.5ha of mangrove wetlands, alongside the loss of 11ha of freshwater wetlands (i.e.,herbaceous freshwater vegetation), due to human activities between 1996 and 2018 (Denyer, 2020).

Aims

The aim of this study is to assess the 'health' of Auckland isthmus wetlands, using data from the Auckland Council (RIMU) biodiversity monitoring program, through the calculation and analysis of multiple indicators of 'environmental condition'. New data collected during field work within the (planted) Kohuora Park wetland will also be assessed using the same environmental indicators. Specifically, my dissertation will address the following questions:

1. What are the most 'useful' environmental indicators for use in monitoring the health of Auckland's wetland ecosystems?
2. What is the most appropriate plot size/ data combination to use in calculating the different environmental indicators?
3. Are there any differences in the plant species richness, diversity and composition of natural vs. constructed/ induced wetlands?
4. Based on the environmental indicators from Aim 1, has there been any significant change in the health of Auckland's urban wetland ecosystems over the 2010 – 2019 period?
5. Are there any differences in wetland health between natural freshwater wetlands, constructed freshwater wetlands, natural coastal wetlands and induced coastal wetlands?

Site Information

Within Kohuora Park is one of the most complex explosive craters located within the Auckland Volcanic field (Hayward, Murdoch, & Maitland, 2011). The Kohuora Volcano measures around 600 meters across and 30 m deep and is considered complex due to its layout which is in a distinctive L to V shape (Figure 13) which was caused by the interaction of explosive eruptions of three to four vents with a large volume of groundwater. According to pollen and sedimentary records after the eruptions (Newham, Lowe, Giles, & Alloway, 2007), a shallow lake was formed within the Kohuora crater, which was then infilled by sediment, followed by the succession of wetland-based vegetation developed peat within the soil deposits that developed the crater into a lacustrine wetland. Unfortunately, within recent years, urbanization had caused a major disturbance in the wetlands, decreasing its size as due to industrial waste disposal and local suburban development. This resulted in deterioration of the wetlands into very small patches of undisturbed areas. However, the New Zealand Department of Conservation designated Kohuora as a protected site as it was recognized to be scientifically important towards paleoenvironmental research in 1995 and the remaining wetlands were acquired by Manukau City (Newham, Lowe, Giles, & Alloway, 2007).

Around 3991ha of land is covered by the Ōtara-Papatoetoe Local Board which is the local council that oversees the restoration and management of around 608ha of parks located within Papatoetoe, Ōtara, East Tamaki and Manukau Central, and subsequently, Kohuora Park (Ōtara-Papatoetoe Local Board, Ōtara-Papatoetoe Local Board ngahere analysis update 2021, 2021). Their policies towards restoration includes the assessment of contaminated land caused by previous landfills (Ōtara-Papatoetoe Local Board, Ōtara-Papatoetoe Open Space Network Plan, 2018), alongside restoration efforts in the board plan of 2020 (Ōtara-Papatoetoe Local Board, Ōtara-Papatoetoe Local Board Plan 2020, 2020).

In the field study, Kohuora Park in Papatoetoe was chosen as there was baseline data from a series of replicate plots collected in 2013 that did not receive its required five-year recording in 2018. It also uses a smaller grid structure compared to the over data samples and was recorded as a replicate. By using these plots, we may be able to ascertain the effectiveness of the restoration progress over the nine- year period. The collected data could also be used as a reference as there is no ten- year iteration of the other plots.

Methods

In this methodology section, it is split into two sections. The first section is used to describe the methodology of the Auckland WMP that was used between the years of 2010 and 2019. The data collected from the WMP between 2010 and 2019 was provided by RIMU and would be referred as RIMU data (Auckland Council/ Auckland Regional Council 2010-2018) (see Appendix 1). The second section is used to describe the methodology for the field work that occurred within one of the WMP plots, Kohuora Park in Papatoetoe.

Wetland monitoring programme methodology

The analysis presented in this dissertation is based on data from a subset of the c. 180 Auckland Council regional wetland monitoring plots. The 39 plots used in my analysis were selected using the following criteria:

1. All wetland monitoring plots that lie within Auckland's Metropolitan Urban Limit (Auckland Regional Growth Forum, 1999) were initially considered for inclusion.
2. Wetland plots for which only baseline data was available (i.e., those established from 2015 onwards) were excluded from the analysis.
3. This left a total of 39 plots with two measures. A baseline measure completed in the period 2010 – 2014, and a five-year re-measure completed in the period 2015 – 2019.

A more detailed description of the methodology used to choose sample locations for the Auckland Council wetland monitoring program, and sampling protocols, is provided in Appendix E. The information in Appendix E is summarised below.

Wetlands were chosen using an 4km x 4km 'wetland grid' superimposed across the Auckland Region. The wetland grid was based on the 8km x 8km national grid used for biodiversity and carbon monitoring by the Department of Conservation (DOC) and the Ministry for the Environment (MfE) (MacLeod, Greene, MacKenzie, & Allen, 2012; Holdaway, et al., 2017). Each 8km x 8km national grid cell was divided into four 4km x 4km wetland grid squares

All 4 km x 4 km grids within Auckland's Metropolitan Urban Limits were checked for the presence of freshwater or brackish wetland ecosystems using existing databases, aerial photographs and field visits. If suitable wetland vegetation was available, a sampling site was established. Where multiple wetlands were present within a single 4km x 4km grid, the wetland closest to the centre-point of the grid was selected for sampling. However, lack of good information about wetland distribution, and the desire to 'bulk-up' sampling of specific types of wetland ecosystems (e.g., constructed wetlands), mean that some 4 km x 4km grids contain multiple wetland samples. The urban wetland dataset used for this dissertation includes seven grids with two wetland samples.

The vegetation sampling plot (one plot per sample site) was randomly located within the chosen wetland prior to arrival at the site. Random plot locations had to be at least 15m from the edge of the mapped wetland to ensure there was enough room to fit in a 15m x 15m plot which was entirely covered by wetland vegetation.

After arrival at the site, vegetation plots were moved if there was no suitable wetland vegetation at the random location. In these instances, the plot was moved to the location closest to the random point which was large enough to accommodate a 15m x 15m wetland plot.

Vegetation monitoring methods summary

The random vegetation plot location point, determined prior to arrival, became the south-west corner of the plot – corner 'P' in Figure 1. Where the vegetation plot needed to be moved due to a lack of suitable wetland vegetation at the random point, or a lack of room for a 15m x 15m plot, the new corner 'P' was located as close as possible to the original random point.

A 15m x 15m sample plot was established with the corner 'P' to corner 'A' plot margin aligned north-south, and the corner 'P' to corner 'M' margin aligned east-west. Magnetic bearings were used. In some cases, the plot orientation had to be adjusted to fit into narrow or small wetlands; if this was done variations to the standard layout were recorded in the plot meta data. Tapes were laid flat, or at a constant height along their length and pulled tight. Tapes were run under windfalls (treefalls) and through clumps of vegetation to ensure the external lines were as straight as practicable. Trees and other woody plants along the plot boundaries were included within the plot if their trunk was predominately (>50%) rooted in it.

The 15m x 15m plot was subdivided into nine 5m x 5m squares by laying out internal tapes (Figure 1). A single 10m x 10m subplot was nested in the south-east quadrant of the 15 x 15m plot. A 2m x 2m sub-plot was established in the middle of each of the nine 5m x 5m subsections (i.e., 1.5 m from the edge of each 5m boundary: Figure 1). Meta data associated with the plot was recorded, and this is outlined in Appendix 1 of this report.

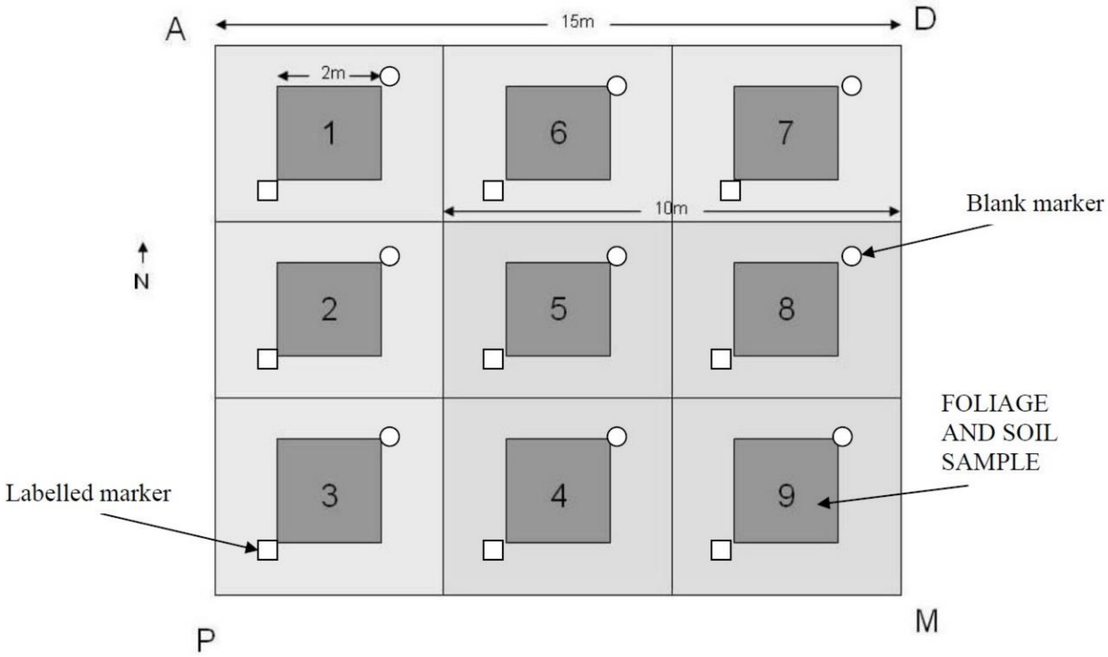

Figure 1: Schematic view of standard wetland vegetation monitoring plot used for the WMP showing the 15m x 15m plot with a 10m x 10m plot (four darker shaded squares in the south-east corner) and nine 2m x 2m plots nested within it.

Within the 15m x 15m plot the presence of live foliage of all vascular plant species was recorded in three height tiers (>2m, 0.3-2m, and <0.3m). Presence of plants with live foliage in two or more s was recorded separately for each height tier in which they occurred. Dead foliage and flowering or fruiting parts of plants were ignored. The presence of any plant species with live foliage within the 15m x 15m plot was recorded irrespective of whether these plants were rooted in the plot or extended into it from a plant that was rooted outside the plot margins.

Within the 10m x 10m plot, the percentage cover of all vascular plant species was estimated in three height tiers (>2m, 0.3-2m, and <0.3m). These percentage cover values were intended as a surrogate estimate of the biomass of foliage per species in each height tier. The percentage cover of dead and live foliage of the same plant species was recorded separately. Percentage cover for plants with live or dead foliage in two or more tiers was assessed separately for each height tier in which they occurred.

The total percentage cover of live or dead foliage was visually estimated by the same observer(s) within each plot. Foliage that hung or leaned into the plot across the plot margins was included, whether rooted within the plot or not. Total plant foliage cover per tier often exceeded 100% due to overlap in plant species[1]. However, multiple (overlapping) layers of the same species within a tier were not summed, which means the maximum value for live or dead foliage of a single plant species within a single tier was 100%.

For the >2m and 0.3 – 2m tiers the maximum height (m) each species in that tier was measured and recorded; with the maximum height of live and dead foliage of the same species recorded separately. Flowering and/ or fruiting parts of plants were not included in the maximum height calculation as they are transient features.

Within each of the nine 2m x 2m sub-plots the presence of live foliage of all vascular plant species was recorded in three height tiers (>2m, 0.3-2m, and <0.3m). Presence of plants with live foliage in two or more tiers was recorded separately for each height tier in which they occurred. Dead foliage and flowering or fruiting parts of plants were ignored.

Plots were established in February/ March 2010 – 2014- and re-measured after five years in February/ March 2015 – 2019.

Metadata was collected at each wetland plot including name, wetland type, tenure, date of sampling, GPS coordinates, land ownership, weather conditions, and wetland system, classification & form. The four corners of the 15m x 15m (or 10m x 10m) wetland plots were physically marked - usually with blue plastic waratah - to identify the four corners. 2m x 2m sub-plots were marked with two marker poles on diagonally opposite corners.

Auckland Council also established replicate wetland plots within several large urban wetland systems, including Kohuora Park, Waiatarua, Soldiers Bay, Onepoto Basin & Le Roys Bush wetlands. The purpose of replicate plot networks was to monitor changes in these individual wetland systems.

[1] For example, within the 0.3 - 2 m tier there could be almost complete cover (say 95%) of reeds at 0.5 m height, a layer of 1.5 m tall rushes emergent over the reeds (30% cover), and a liana species climbing through the rushes and reeds from 0.3 – 1.5m (15% cover). This would sum to a total cover of 140% in the 0.3 – 2m tier.

Replicate plots were 10m x 10m in size and sampled using a methodology identical to that outlined for the nested 10m x 10m plot above. However, due to their smaller size the replicate plots contained only four (as opposed to nine) 2m x 2m sub-plots. Re-measurement of replicate plots by the Auckland Council has been more ad-hoc and not always using the same five-yearly measurement cycle of the grid plots. One of these replicate plot networks – the four plots within Kohuora Park – were chosen for re-sampling as part of my dissertation. These replicate plots had not been measured for nine years. More detail on the methods used to sample the Kohuora Park plots is provided in the next section.

Field Work Methodology

Vegetation Plot Selection

As the Kohuora Park has been chosen the wetland site for study, only the plot areas were required. By using GPS coordinates that were used to mark the specific monitored plot locations from 2013, random plots were chosen, respectively named KOHREP2, KOHREP3, KOHREP4, and KOHREP5. Arrival on each plot location required visual identification the blue marker pole which dictated the south-west corner of the plot alongside the GPS confirmation. Due logistical issues and difficulty of site access, this has made some data collection from some plot points within Kohuora park difficult, mainly due to immense growth of blackberry (*Rubus fruticosus*) shrubbery that surrounded some plots. The density of the blackberry shrubs was thick and high, reaching up to nearly 2m, and was incredibly thorny. Some plot sites also required careful navigating due to the wetland aspect as to not travel through channels and avoiding wasp nests.

Vegetation Monitoring Methods

Unlike the WMP monitoring methods, these replicates used a different grid size, using 10 x 10 m sample plot instead of the 15 x 15 m. However, the structure of the plot is exactly the same, just on a smaller scale. Using the blue stick corner marker as grid reference, alongside a compass and tape measure, a 10 x 10 plot was established following WMP methodology, marking each corner with their respective alignment used in the WMP 15 x15m plot. The 10 x 10m plot was then divided into four 5 x 5m plot. It is then subdivided further into 2 x 2m plots in the centre of each 5 x 5m plot. Each 5 x 5m plot was labelled into quadrants, Q1 to Q4 respectively. This helps keep track of which quadrant is currently being recorded within the 2 x 2m plots that is nestled in each 5 x 5 m plot. Recording the data always begins at Q1 which begins at the 'P' corner then moves in a clockwise fashion towards the Q2 at 'A' corner, Q3 at 'D' corner and Q4 at 'M' corner, then returning to Q1 (see Figure 2).

In terms of data recording, WMP recording methodology for the 10 x 10m plots and 2 x 2m plots were followed. The 10 x10m plots recorded the percentage cover of all vascular plants, their estimated height tiers (>2m, 0.3-2m, and <0.3m) max height (if applicable) and live or dead status, ignoring flowering and/ or fruiting plant parts. Same plant species with different height tier and different live or dead status were recorded separately. The 2 x 2m plots recorded the percentage cover of all live vascular plants and their estimated height tiers while dead foliage alongside flowering and / or fruiting plant parts were ignored.

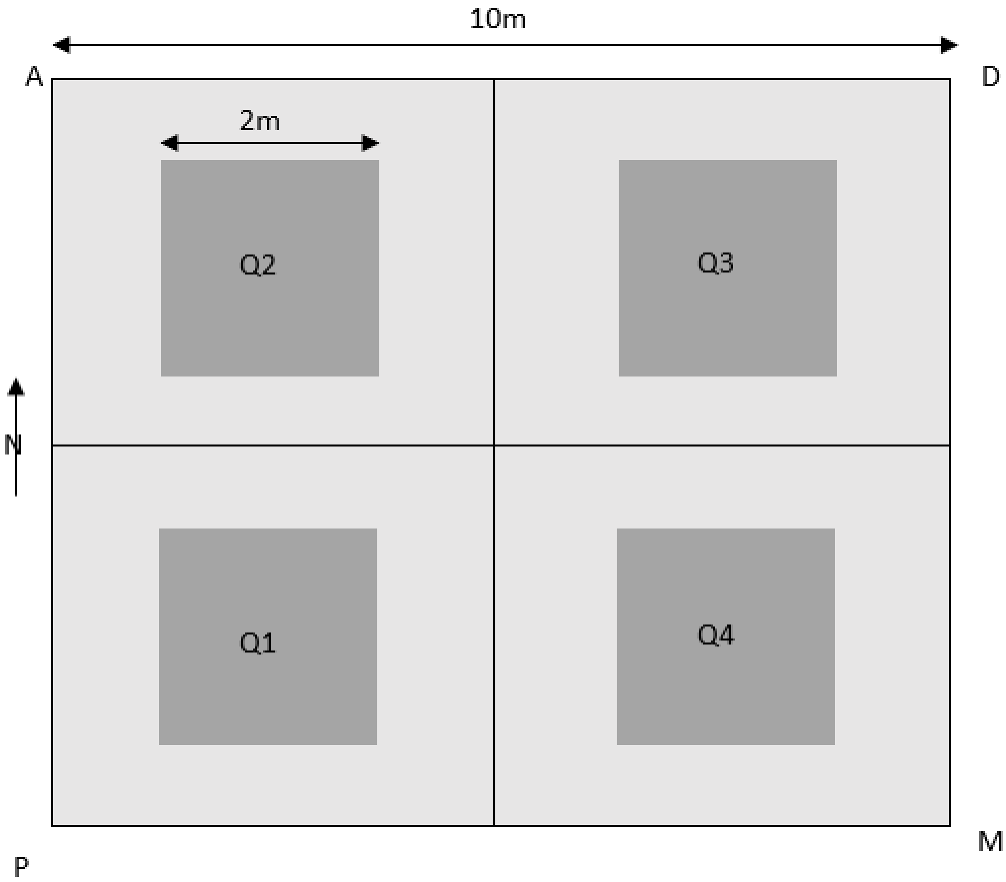

Figure 2: Schematic view of the vegetation monitoring plot used for the Kohuora Park plot sample, showing the 10 x 10m plot, divided into four quadrants (Q1-Q4) with 2 x 2m plots nestled in the centre of each quadrant

Figure 2: Schematic view of the vegetation monitoring plot used for the Kohuora Park plot sample, showing the 10 x 10m plot, divided into four quadrants (Q1-Q4) with 2 x 2m plots nestled in the centre of each quadrant.

For this data, it follows WMP metadata recording methodology, recording the name of the site, wetland type, date, GPS coordinates, landowner, weather conditions, and wetland system, classification and form.

Statistical Analysis

Statistical analyses were undertaken using Microsoft Excel. Differences between wetland types were assessed using one-way ANOVA tests. Differences between the baseline measurement and the five (or nine) year re- measures of the same plots were assessed using paired sample t-tests. Post hoc tests were used to analyse the significance between the two wetland types of any significant ANOVA tests. The Post hoc test used was the Bonferroni Correction.

Results

Auckland WMP vegetation collection and analysis

The data collected from urban wetland plots in the WMP over a ten-year period (2010 – 2019) was provided by RIMU (Auckland Council unpublished data). The dataset included information from 39 different wetland plots from the 4km x 4 km 'wetland grid' that was superimposed across the Auckland region (see Appendix 1 & Table 1). Note that not all wetland plots have a second observation (i.e., the five-year remeasure) as the dataset extends only to 2019 so, any wetland plots that have had begun its monitoring process in 2015 or lack a second dataset in the latter years is not included in data analysis as there is no data to compare the vegetation change. The wetland plots from the dataset are M23, M27A and M27B as their initial recording date began in 2015 and 2018 and lack a secondary recording. The O26 plot was excluded from some data used in the indicators as it lacked recordings of the 10 x 10m and 2 x 2m plots in the 5-year recording but is used in indicators that had required 15 x15m plots. M22 plot lacked a 15 x15m plot reading for the re-measure but had the recordings for 10 x10m and 2 x 2m plots. Thus, the plot data compiled was not used in the analysis of some indicators. Excluded plots are marked with an asterisk in Table 1.

Table 1: Auckland Council urban wetland plots

WETNU	NAME	WETLAND TYPE	DATE of Establishment	ACTUAL GPS_E	ACTUAL GPS_N	W_SYS	W_SUB	W_CLA	W_FORM
K24A	Coastal - West Harbour	Coast - induce	02/03/15	1746435	5924792	PALUSTRIN	PERMANENT	SWAMP	FLAT
K25	Coastal - Central Park Drive	Coast - induce	09/03/17	1746030	5918916	PALUSTRIN	PERMANENT	SWAMP	CHANNEL
L24	Coastal – Harbourside	Coast - induce	10/03/16	1748061	5921503	PALUSTRIN	PERMANENT	SWAMP	FLAT
Q25	Tahuna-Torea	Coast - induce	03/03/16	1767835	5917747	PALUSTRIN	EPHEMERAL	MARSH	FLAT
K24B	Coastal - Moire Park	Coast - natural	06/03/19	1745513	5923354	ESTURARI	PERMANENT	SALTMARSH	MUDFLAT
L25	Traherne Island	Coast - natural	07/03/19	1749742	5917888	PALUSTRIN	PERMANENT	MARSH	FLAT
M24C	Coastal - Soldiers Bay	Coast - natural	04/03/19	1751690	5924516	PALUSTRIN	PERMANENT	SWAMP	CHANNEL
N23	Coastal – Takapuna	Coast - natural	02/03/16	1757632	5926903	PALUSTRIN	PERMANENT	SWAMP	FLAT
N24A	Coastal - Shoal Bay	Coast - natural	07/03/16	1759103	5924994	PALUSTRIN	PERMANENT	SWAMP	CHANNEL
N28	City fringe – Stonefields	Coast - natural	01/04/15	1756012	5905793	PALUSTRIN	EPHEMERAL	EPHEM. WE	BASIN
N29	Coastal - airport light industry	Coast - natural	14/03/18	1758164	5905315	PALUSTRIN	PERMANENT	SWAMP	CHANNEL
O25	Coastal - Hobson Bay	Coast - natural	07/03/16	1760054	5918316	PALUSTRIN	PERMANENT	SWAMP	BASIN
O28	Coastal – airport	Coast - natural	01/03/16	1760306	5905561	PALUSTRIN	PERMANENT	SWAMP	BASIN
P30	City fringe – Puhinui	Coast - natural	24/03/15	1763684	5901007	PALUSTRIN	EPHEMERAL	EPHEM. WE	FLAT
J24	City fringe - Waitak foothills	FW natural	04/04/18	1741173	5923176	PALUSTRIN	PERMANENT	MARSH	CHANNEL
J25	City fringe - Waitak foothills	FW natural	25/02/19	1741495	5921333	PALUSTRIN	PERMANENT	SWAMP	CHANNEL
J26	City fringe - Waitak foothills	FW natural	16/03/17	1742687	5913769	PALUSTRIN	PERMANENT	SWAMP	CHANNEL
M23*	Eskdale	FW natural	02/04/15	1753444	5926289	CLOUDY	RIVERINE	PERMANENT	SWAMP
M24A	Birkenhead (Clements Bay)	FW natural	02/03/15	1752293	5923395	PALUSTRIN	PERMANENT	MARSH	FLAT
M24B	Le Roys wetland (FW part)	FW natural	07/03/19	1754925	5924225	ESTURARI	PERMANENT	EPHEM. WE	CHANNEL
M27A*	Wattle Bay	FW natural	10/04/18	1753739	5911094	PALUSTRIN	PERMANENT	SWAMP	CHANNEL
O27A	Grotto wetland	FW natural	04/03/15	1760062	5912525	PALUSTRIN	EPHEMERAL	MARSH	BASIN
O29	City fringe - Pukaki crater	FW natural	03/04/18	1761126	5905333	ESTURARI	PERMANENT	SALTMARSH	MUDFLAT
K27	Park Konini	FW restored	30/03/15	1746604	5912226	PALUSTRIN	PERMANENT	SWAMP	CHANNEL
M22*	Unsworth Downs	FW restored	08/03/16	1753095	5930854	PALUSTRIN	PERMANENT	SWAMP	CHANNEL
M27B*	Park Hillsborough	FW restored	29/03/18	1753272	5912485	PALUSTRIN	EPHEMERAL	MARSH	BASIN

N20A	City fringe - Long Bay	FW restored	08/03/16	1755976	5939186	PALUSTRIN	EPHEMERAL	MARSH	FLAT
N20B	City fringe - Long Bay	FW restored	05/03/18	1756078	5939775	PALUSTRIN	PERMANENT	SWAMP	CHANNEL
N24B	Onepoto Crater	FW restored	27/02/19	1756274	5925099		EPHEMERAL	SALTMARSH	BASIN
O26*	Waiatarua	FW restored	03/03/15	1762580	5916378	PALUSTRIN	PERMANENT	SWAMP	FLAT
O27B	Anns Creek stormwater	FW restored	03/03/16	1763058	5911384	PALUSTRIN	PERMANENT	SWAMP	BASIN
P28A	Kohuora Park	FW restored	23/03/15	1763821	5905848	PALUSTRIN	PERMANENT	SWAMP	FLAT
P28B	Manukau Sportsbowl	FW restored	02/03/16	1767577	5905628	PALUSTRIN	PERMANENT	SWAMP	CHANNEL
Q26	Pigeon Mountain Park	FW restored	30/03/15	1769272	5915601	PALUSTRIN	EPHEMERAL	EPHEM. WE	BASIN
Q28	East Tamaki	FW restored	16/03/15	1770593	5908773	PALUSTRIN	EPHEMERAL	EPHEM. WE	CHANNEL
KOHREP2	Kohuora Park	FW restored	16/02/2022	1763891	5905676	PALUSTRIN	PERMANENT	SWAMP	FLAT
KOHREP3	Kohuora Park	FW restored	18/02/2022	1763877	5906002	PALUSTRIN	PERMANENT	SWAMP	FLAT
KOHREP4	Kohuora Park	FW restored	18/02/2022	1763876	5905795	PALUSTRIN	PERMANENT	SWAMP	FLAT
KOHREP4	Kohuora Park	FW restored	18/02/2022	1763931	5905766	PALUSTRIN	PERMANENT	SWAMP	FLAT

Each wetland plot is categorised into four types of wetlands, Coast-induced, Coast- Natural, Fresh Water-Natural and Freshwater- Restored. Coastal wetlands is a broad term used to describe wetland ecosystems that are located close to a coastal zone. Despite using the term coastal, the wetland hydro systems of these areas can be freshwater or saltwater. Wetlands located directly on the coastline or within the tidal zone of streams, creeks and estuaries were classified as 'Coastal' wetlands. Coastal wetlands that were present in 1940's aerial photographs of the Auckland isthmus were classified as 'Coast-natural'. Coastal wetlands that had appeared since 1940, which were all the result of active planting or altered hydrology (e.g., from a dam caused by a road bund), were classified as 'Coast-induced'.

Freshwater (FW) wetlands represent the term for inland wetlands that have mainly freshwater hydro systems. The term induced is referring to wetlands that have been created unintentionally by human activities (Ministry for the Environment, Defining 'natural wetlands' and 'natural inland wetlands', 2021). The term restored is used to describe wetlands that have been artificially constructed, effectively a constructed wetland, and is not categorized as a 'natural wetland'. Freshwater wetlands that were present in 1940's aerial photographs of the Auckland isthmus were classified as 'Freshwater-natural'. Note that 'natural' does not imply anything about the quality or native dominance in the wetland systems. For example, the 'natural' class included several valley bottom wetlands within exotic pasture on the urban fringe (i.e., still within the Auckland metro area) that were dominated by exotic herbaceous plants. However, as these wetlands had not been cleared and re-planted in the last c. 80 years they were still classified as natural systems for the purposes of this study. Freshwater wetlands that had appeared since 1940 as a result of active planting, or which had obviously been cleared of their former exotic-dominated wetland vegetation and re-planted with native species, were classified as 'Freshwater-restored'.

Indicator analysis

Indicator 1: Species richness

A total of 268 vascular plant species and sub-species have been recorded across the ten years of wetland sampling to date (2010 – 2019). In the Kohuora Park (KOH) dataset, a total of 52 vascular plant species and sub-species were recorded between the date of 2013 to 2022 and a list of these species is provided in Appendix A. The species total includes data from all plots, including both regional grid wetland plots within the Auckland metropolitan area, and KOH plots. 141 exotic vascular plant species and 127 native species were recorded across all the urban wetland plots used for this study. In the KOH dataset, 23 species are exotic and 29 were native. During plot measurement, some plants were unable to be identified to species level and were recorded as unknown, to the genus level only (e.g., Carex sp., Juncus sp.) or within some other grouping (e.g., UNID native fern). Species recorded in these higher-level groupings were not included in the totals above, or in Appendix A data.

Table 2 presents summary values for species richness within Auckland urban wetland plots. The average species richness of plants in Auckland urban wetland plots is presented in Figure 2. Unsurprisingly, more plant species were recorded in 15m x 15m(225m^2) plots compared with the 10 x10m(100m^2) and the nine 2 x 2m (36m^2) plots as they are nestled within the 15 x 15m plots and have a smaller plot area. The 10 x10m plots have a smaller species richness than the nine 2 x 2m plots as five of the nine 2 x 2m plots are located outside the 10 x 10m plots, thus having a wider range (Figure 1).

The most species rich plot (57 species) recorded across all 31 grid wetland plot measurements was 1st remeasure of plot K27, which occurred after 5 years(T1). This is a palustrine wetland categorized as a freshwater -restored wetland, is located in Kowhai Park Konini. The baseline measure of this plot was 36 species, which was the second highest species richness in the baseline measures. There was no significant difference between the baseline and 5-year measurement (t= 0.69, n =31, Significance >0.05).

The most species poor plot was both measurements of N24A (3 species and 4 species respectively), which is natural palustrine wetland, categorized as a natural coastal wetland and is located in Little Shoal Bay reserve. The dominant species of this plot were *Bolboschoenus, Calystegia sepium x silvatica & Typha orientalis* in the baseline measurement, while the re-measurement had *Bolboschoenus fluviatilis, Calystegia sepium x silvatica, Cortaderia jubata & Typha orientalis.* The wetland is in the brackish zone in the upper reaches of a small tidal creek. It is <2m above the sea level and only 15m inland of the 'mangrove line'.

Tables 3-6 represent the summary values for species richness of each respective wetland type that was found in the WMP plot data. These wetland types are sorted and categorized as Coastal wetlands induced, Coastal wetlands natural, Freshwater natural and Freshwater restored respectively.

Table 7 presents the summary values for species richness within the KOH plots. Average species richness is these plots are presented in Figure 4. It must be noted however, the baseline recording(T0) for KOH plots lacks the four 2 x 2m plot recordings for unknown reasons. Using the data from T2 (+9 years), it can be seen unsurprisingly that the 10 x 10m plots in both the T0 and T2 have a higher species richness than the four 2 x 2m plots in T2. The most species rich plot (28 species) that is recorded across the four KOH plots measurements is the baseline recording of KOHREP2. The most species poor plot(9species) that was recorded was KOHREP3 in the T2 data. KOH datasets are located within Kohuora Park in Papatoetoe and is a palustrine swamp that is categorized as a FW restored wetland. The difference between native species richness in the baseline recording and the 9-year re-measure are significant (t= 3.81, n = 4, significance < 0.05). Some pictures of the plot locations can be seen in Figures 12

Table 2: Species richness for all Auckland Council urban wetland plots (n= 31)

Plot size	Measure	Richness (all plant species)				Richness of native species				Richness of exotic species			
		µ	Max	Min	Med.	µ	Max	Min	Med.	µ	Max	Min	Med.
15m x 15m	T0 (baseline)	18.39	37	3	18.39	7.45	22	1	6	10.94	30	0	10
10m x 10m		13.36	26	1	13	5.42	16	0	5	7.84	22	0	8
Nine 2m x 2m		13.97	31	3	14	5.65	17	0	5	8.32	20	0	7
15m x 15m	T1 (+ 5 years)	19.39	57	4	18	8.1	22	2	6	11.29	35	1	10
10m x 10m		13.68	45	4	12	5.77	18	1	5	7.9	28	0	7
Nine 2m x 2m		13.74	44	3	13	5.97	16	2	5	7.77	29	0	7

Table 3: Species richness of Coastal Wetlands - Induced plots (n= 4)

Plot size	Measure	Richness (all plant species)				Richness of native species				Richness of exotic species			
		µ	Max	Min	Med.	µ	Max	Min	Med.	µ	Max	Min	Med.
15m x 15m	T0 (baseline)	21.5	26	18	21	5.75	10	4	4.5	15.75	21	14	14
10m x 10m		14.25	16	12	14.5	3.75	7	1	3.5	10.5	14	8	10
Nine 2m x 2m		15.5	16	14	16	4.75	7	4	4	10.75	12	7	12
15m x 15m	T1 (+ 5 years)	21.75	26	18	21.5	7.5	10	5	7.5	14.25	16	12	14.5
10m x 10m		14	17	13	13	4.75	8	3	4	9.25	10	8	9.5
Nine 2m x 2m		14	16	13	13.5	4.25	5	3	4.5	9.75	11	9	9.5

Table 4: Species Richness of Coastal Wetlands - Natural Plots (n =10)

Plot size	Measure	Richness (all plant species)				Richness of native species				Richness of exotic species			
		µ	Max	Min	Med.	µ	Max	Min	Med.	µ	Max	Min	Med.
15m x 15m	T0 (baseline)	13.5	26	3	13.5	8.1	22	2	7	5.4	14	0	14.5
10m x 10m		9.8	25	1	8.5	6.3	16	1	5.5	3.5	13	0	2
Nine 2m x 2m		11.2	24	3	11	6.5	17	2	5	4.7	12	0	4
15m x 15m	T1 (+ 5 years)	14	25	4	11	7.5	17	2	6	6.5	13	1	6.5
10m x 10m		9.3	22	4	7.5	5.3	10	2	4	4	12	0	3.5
Nine 2m x 2m		10.3	21	3	7	6.1	16	2	4	4.2	8	0	4.5

Table 5: Species richness of Freshwater Wetlands - Natural Plots (n = 7)

Plot size	Measure	Richness (all plant species)				Richness of native species				Richness of exotic species			
		µ	Max	Min	Med.	µ	Max	Min	Med.	µ	Max	Min	Med.
15m x 15m	T0 (baseline)	16.57	25	9	19	7	19	1	6	9.57	21	1	8
10m x 10m		11.86	21	7	10	5	10	0	5	6.86	17	0	4
Nine 2m x 2m		12.43	22	6	12	5	12	1	5	7.43	18	1	6
15m x 15m	T1 (+ 5 years)	19.71	44	7	14	8.29	18	2	7	11.43	26	2	7
10m x 10m		12.14	19	8	12	5.29	9	1	5	6.86	15	2	5
Nine 2m x 2m		13.29	29	5	10	6.17	13	2	5	8	4	5	10

Table 6: Species Richness of Freshwater Wetlands- Restored plots (n = 10)

Plot size	Measure	Richness (all plant species)				Richness of native species				Richness of exotic species			
		µ	Max	Min	Med.	µ	Max	Min	Med.	µ	Max	Min	Med.
15m x 15m	T0 (baseline)	23.3	37	10	22	7.8	21	2	7	15.5	30	8	15
10m x 10m		17.73	26	10	16	6.18	13	1	6	11.55	22	7	10
Nine 2m x 2m		17.81	31	8	17	7.1	15	2	6.5	11.36	20	5	11
15m x 15m	T1 (+ 5 years)	23.6	57	13	20.5	8.8	22	3	7	14.8	35	8	12
10m x 10m		19	45	9	17	7	18	1	5	12	28	5	10.5
Nine 2m x 2m		17.4	44	9	14.5	7	15	2	5	10.4	29	4	8.5

Table 7: Species richness for Kohuora Park Plots (n = 4). 2 x 2m plots for the baseline measurement was not found.

Plot size	Measure	Richness (all plant species)				Richness of native species				Richness of exotic species			
		µ	Max	Min	Med.	µ	Max	Min	Med.	µ	Max	Min	Med.
10m x 10m	T0 (baseline)	19.50	28	9	20.5	9.5	14	3	10.5	10	17	6	8.5
Four 2m x 2m													
10m x 10m	T2 (+ 9 years)	14.00	17	9	15	6.25	10	2	6.5	7.75	10	7	7
Four 2m x 2m		9.25	13	6	9	3.75	6	1	4	5.50	8	4	5

Table 8: Average species richness for 15 x 15m plots across wetland types (n = 32)

INDICATOR 5 – Weed Dominance	T0 (Baseline)	STDEV	Std Error	T1 (+5 years)	STDEV	Std Error
Coastal wetlands induced (n = 4)	21.5	4.12	2.06	21.75	4.35	2.17
Coastal wetlands natural (n = 10)	13.5	7.93	2.51	14	8.01	2.53
FW natural (n = 4)	16.57	6.19	2.34	19.71	12.09	4.57
FW restored (n = 10)	23.3	9.03	2.87	23.6	13.38	4.23

The summary results in Tables 2 to 7 show that the 15m x 15m plots have significantly higher species richness totals than the two smaller plot sizes. There was no significant difference in average species richness between data collected from a single 10m x 10m plot vs. nine 2m x 2m plots. Higher species richness for the 15m x 15m plot is not unexpected given that it is more than twice as large as the 10m x 10m plot (225m^2 vs. 100m^2).

While the nine 2m x 2m plots covered only one third the area of the 10m x 10m plot (36m^2 vs. 100m^2) they had a very similar species richness. This seems contrary to the previous result where the larger plot sizes had a significantly higher species richness. However, while the 2m x 2m plots had a smaller total area than the 10m x 10m plot they were more widely dispersed in space (Figure 1) meaning they were more likely to include additional plant species. The species-area relationship is one of the most observed ecological 'laws' (Preston, 1960; Lomolino, 2001). Allowing us to understand that a larger habitual area, would allow for a higher or denser species diversity. As such, 15m x15m plots is the most appropriate plot to use in this indicator as it contains the most recording instances of plant species.

In Table 7, the data shows inconclusive results in terms of the 2 x 2m plot recordings as there is lack of 2 x 2m data recordings in the T0 baseline dataset. However, the T2 recordings are different than the WMP plots, as only four 2 x 2m plots were recorded. There is a difference in species richness between a single 10 x 10m and four 2 x 2m plots as the total area of these plots is significantly different (100m^2 vs. 16m^2). This is due to the difference in the number of 2 x 2m plots compared to the WMP as their five of their 2 x 2m plots are located outside of the 10 x 10m plots. Having only four 2 x 2m plots has greatly reduced the species richness as the total area recorded are significantly different (36m^2 vs. 16m^2).

The Coastal -Induced wetlands class has the second highest average for total species richness in both measures (21.5 & 21.75 respectively) (Table 3 and Figure 3 &4). However, most of these species were exotic plants as this class also had the lowest average native plant species richness of 5.75 in the baseline measurement, and 7.5 in the 5-year remeasurement. There was no significant difference between the baseline and five-year measures for average native species richness (t = 2.05, n = 4, Significance > 0.05) for this class. Coastal – induced wetlands had the highest average of exotic plant species richness in the baseline measurement (15.75) across all wetland types and 14.15 in the 5-year remeasurement. There was no significance in average exotic plant species richness (t = 1.04, n =4, Significance >0.05) across the five-year period between measures.

Coastal Wetlands- Natural has the lowest total species richness among all wetland types in the baseline measurement (13.5) and 5 -year remeasure (14) (Table 4 and Figure 3). There was no significant difference (t = 0.45, n =10, Significance > 0.05) in total vascular plant species richness between two measures. This wetland type also had the lowest exotic species richness in both measures (5.4 and 6.5 respectively) which also showed no significant difference between measures (t = 1.19, n = 10, Significance > 0.05). The average native plant species richness differences between measures was also not significant (t = 0.84, n =10, Significance > 0.05)

Table 5 and Figure 3 presents the summary of species richness for Freshwater wetland- Natural, which has the average native plant species richness of 7 and 8.29 in the baseline measurement and 5-year remeasurement respectively. There is no significant difference between the measurements for average native plant species richness (t = 0.65, n = 7, Significance > 0.05). The average exotic plant species richness in the baseline measurement is 9.57, while the remeasurement is 11.43. There is no significant differences between measures (t = 0.76, n = 7, Significance > 0.05).

Table 6 and Figure 3 presents Freshwater wetlands – Restored, which has the highest species richness across all wetland types and measures (23.3 & 23.6 respectively). This wetland type has the second highest native species richness in the baseline measures (7.8) but has the highest 5-year measurement (8.8). However, these the difference between the two measures for average native plant species are not significant (t = 0.48, n = 10, Significance > 0.05). It has the highest average of exotic plant species richness in the 5-year remeasurement across all wetland types (14.8). It has the second highest average exotic species richness of 15.5 in the baseline measurement, but there are no significant differences between the measures (t = 0.35, n = 10, Significance > 0.05)

ANOVA significance tests were used to analyse the significance of the differences of average species richness between wetland types. It was shown that there were significant differences in average species richness between wetland types (f= 3.07, n = 31, Significance < 0.05) in the baseline measure. However, no significant differences between wetland types were detected in the 5-year remeasures (f = 1.41, n = 31, significance > 0.05). There is also no significance between average native plant species richness between wetland types in the baseline measures (f value = 0.21, n =31, Significance > 0.05) and 5 -year remeasurement (f value = 0.12, n = 31, Significance > 0.05).

However, there was a significant difference between wetland types in the average exotic species richness for the baseline measurement (f = 5.49, n = 31, Significance < 0.05). Post hoc analysis revealed that the Coastal Wetlands -Induced has a significantly higher exotic plant species average than Coastal Wetlands -Natural (P value < 0.008). It also revealed that Coastal Wetlands -natural has a significantly higher exotic plant species average than Freshwater wetlands -Restored (P value < 0.008). There was no significance between wetland types in the 5-year remeasure (f value = 2.70, n=31, Significance > 0.5).

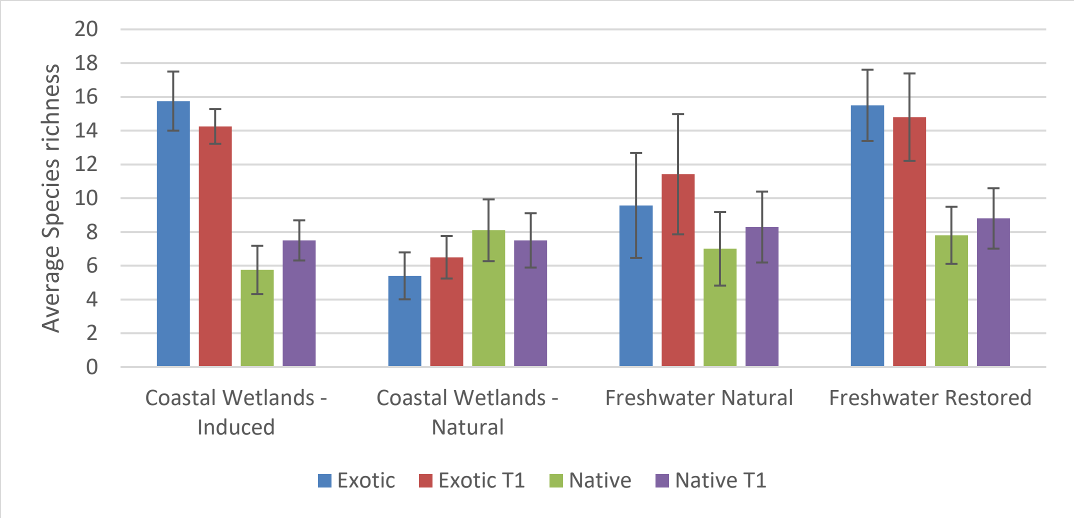

Figure 3: Average exotic & native species richness of the 15m x 15m Auckland Council wetland plots. Data is sorted by their wetland types and measures.

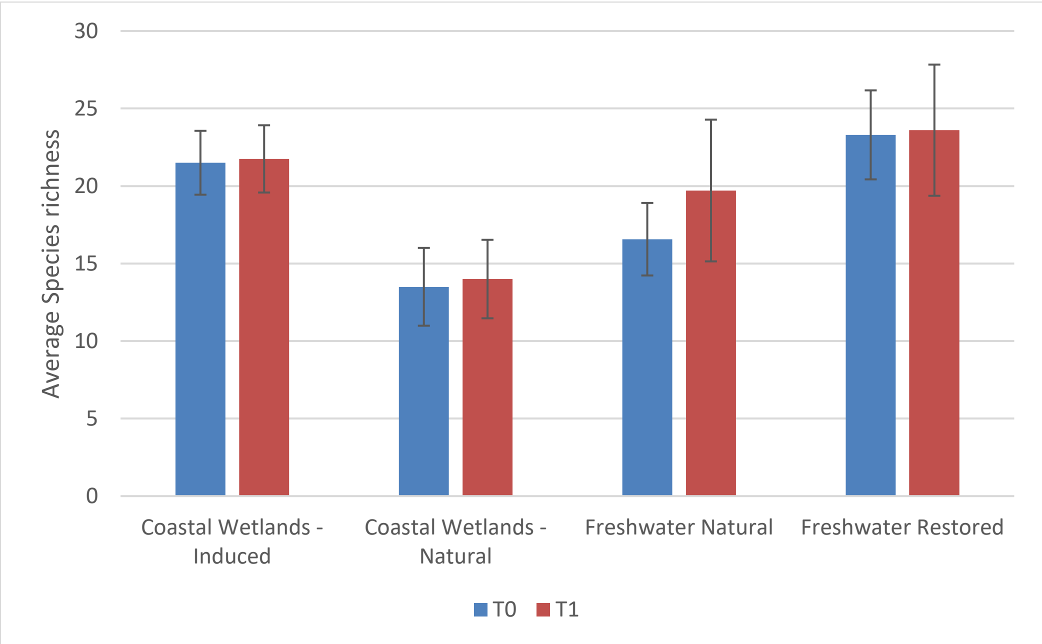

Figure 4: Average species richness of the 15m x 15m Auckland Council wetland plots. Data is sorted by their wetland types and measures.

Indicator 2: Naturalness (species richness)

Naturalness provides a broad indicator of the balance between exotic and native plant species within the urban wetland ecosystems measured as part of this study. This balance can be calculated using a variety of different metrics, but in this case the 'naturalness (species richness)' indicator uses native vs. exotic species richness.

The indicator value for each plot was calculated by dividing the total number of indigenous vascular plant species recorded in the plot by the total number of exotic vascular plant species, and then calculating the average from all plots or plot groupings.

Initial values for this indicator ranged from 0 – 26. Eight plot location/ size combinations had no exotic species in them and therefore the native: exotic species ratio was unable to be calculated numerically. The initial results were scaled by setting the maximum value of naturalness at 10. Ten was chosen as the maximum value because plots with naturalness values of greater than 10 were all the result of a single exotic species being present in a plot with a native plant diversity of greater than 10 species. That is, results of >10 on this indicator were the result of a higher native plant diversity rather than a higher naturalness. The 7 plots with no exotic species recorded in them were all assigned the maximum naturalness value of 10.

Table 10 presents the summary of 'naturalness' indicator values for Auckland Council urban wetland monitoring sites, calculated from each wetland plot within the dataset and sorted into their respective wetland types and plot sizes. As can be seen in Table 9, Coastal wetlands induced have the lowest 'naturalness' indicator compared to the other wetland types, which indicate that their native: exotic species ratios is skewed towards exotic species which is unsurprising as these wetlands are created as result of human disturbance. This may be due to the relationship between human disturbance and establishment of exotic species (Lozon & MacIssac, 1997). The wetlands that hold the highest 'naturalness' indicator would be the Coastal wetlands natural plots. This may be due to multiple plots (7 plots) within the wetland type that was assigned the maximum naturalness of 10 due no exotic species that were recorded.

It can be seen in Table 10 that some of 10 x 10m plots have a higher 'naturalness' indicator than the 15 x 15m and nine 2 x 2m plots except for coastal wetlands- induced (baseline), Freshwater -natural (baseline) and Freshwater -restored (baseline and T1). This is due to the different total area of each plot size, as the larger the plot size, the more species recorded into the measurement. It is clear to see that there is a higher inclusion of exotic species within the 15 x 15m plot measurements as their 'naturalness' value is lower than the 10 x 10m plots, which show a higher 'naturalness' value as there were less exotics species found within their plot. It is similar with the nine 2 x 2m plots as their total area is much larger than the 10m x 10m plots.

There is a change in indicator values between the baseline measure and the 5-year re-measure, as some wetland types have increased or decreased in 'naturalness' value but was found to be not significant (t= 1.72, n = 31, Significance > 0.05). There is also a no significance in 'naturalness' indicator values between wetland types in baseline measures (f value= 1.69, n = 31, Significance > 0.05) and 5-year remeasures (f value = 1.11, n=31, Significance > 0.05). In coastal wetlands -induced, its 'naturalness' indicator values showed a difference between the measures but was found not to be significant (t= 1.55, n = 4, Significance > 0.05). However, there is a decrease in 'naturalness' value in the 2m x 2m plot, despite the increase in the other plot observations. Coastal wetlands natural showed the largest decrease in 'naturalness' value in the among the 15m x 15m and 10m x 10m plots, from 2.67 in the 15 x15 m plot to 1.83 and 4.05 to 2.67 respectively. In the 15m x 15m and 10m x10m plots, the differences between 'naturalness' value between measures was not significant (15m x 15m plot* t = 1.64, n = 10, Significance > 0.05; 10m x 10m plot* t= 1.57, n = 10, Significance > 0.05 respectively). Freshwater Natural also showed a decrease in value in the five-year re-measure (2.35 to 1.62) in the 15m x 15m plot but with no significance (t = 1.07, n =7, Significance > 0.05). Freshwater restored wetland plots are the only plots in Table 9 to have an increase in 'naturalness' value across all plots. This differences between measures were not significant (t= 0.90, n = 10, Significance > 0.05)

Table 11 presents the summary data of the 'naturalness' indicator values of the KOH plots. Unlike the full dataset, which was sorted by wetland types, all of the KOH plots are located within a single wetland within the restored Freshwater wetlands ecosystem class. No 15m x 15m data is provided for KOH plots as this plot size was not used for replicate plots. In addition, there were no 2 x 2m plot recordings for the T0 baseline. The reason for this is unknown as this data it was collected by RIMU. While the average 'naturalness' indicator is higher or baseline measures, compared to the nine-year re-measures, this difference was not significant (t stat = 0.561, n=4, significance >0.05). However, it can be seen in the 10 x 10m plots that there is a significant change in 'naturalness' in KOHREP4 in which the T2 (+9 year) indicator recording had decreased significantly compared to the baseline recording (1.67 vs 0.7). In the KOH dataset, the number of exotic and native species of KOH had changed from 6 exotics species and 10 native's species to 10 exotic species and 7 native species over the span of 9 years.

Table 9: Vascular plant species richness in Kohuora Park replicate plots across two plot measures

	Recorded in baseline measure only	Recorded in re-measure only	Recorded in Both measures	Total
Exotic Vascular plants	9	3	11	23
Native Vascular plants	14	3	12	29
TOTAL	23	6	23	52

Table 10: Average 'Naturalness' indicator values for Auckland Council urban wetland monitoring plots. Data includes baseline values and a five-year re-measurement. Wetland plots grouped into four general classes on the basis of their origin and ecology

INDICATOR 2 – Naturalness	T0 (Baseline)			T1 (+5 years)		
	15 x 15	10 x 10	2 x 2	15 x 15	10 x 10	2 x 2
All plots (n =31)	1.59	2.05	1.70	1.22	1.47	1.31
Coastal wetlands induced (n =4)	0.38	0.41	0.50	0.52	0.53	0.44
Coastal wetlands natural (n =10)	2.67	4.05	2.76	1.83	2.67	2.19
FW natural (n = 7)	2.35	2.44	2.54	1.62	1.48	1.25
FW restored (n = 10)	0.54	0.59	0.63	0.60	0.65	0.81

Table 11: Average 'Naturalness' indicator values for Kohuora Park wetland monitoring plots. Data includes baseline values and a nine-year re-measurement. 2 x 2m plots for the baseline measurement was not found.

INDICATOR 2 – Naturalness	T0 (Baseline)		T2 (+9 years)	
	10 x 10	2 x 2	10 x 10	2 x 2
All plots (n = 4)	1.02		0.82	0.73
KOHREP2	0.65		0.86	0.6
KOHREP3	0.5		0.29	0.2
KOHREP4	1.67		0.7	0.63
KOHREP5	1.27		1.43	1.5

Indicator 3: Naturalness (biomass)

The 'naturalness (species richness)' indicator values presented in the previous section take no account of the relative biomass of exotic vs. native plants within WMP plots. That is, presence of a single seedling <10cm tall would have the same impact on the final naturalness (species richness) indicator score as a thick, 2m high sward of the same species across the entire plot. The 'naturalness (biomass)' indicator incorporates data on the relative biomass of wetland plants (Native, Exotic and Total biomass) using % cover estimates carried out in the field as part of the plot measurement (for 10m x 10m plot data). The naturalness (biomass) indicator also uses tier height as a surrogate for biomass by assigning a larger biomass value for species recorded in higher tiers.

As 15m x 15m and 2m x 2m plot data was based on presence/ absence of plant species in tiers, and no cover or relative dominance information was collected, these plot sizes were not suitable for calculating naturalness (biomass). Naturalness (biomass was calculated for each plot measure using the relative biomass of Native plant species and Total species biomass (Native biomass/ Total biomass). This indicator value provides an estimate the proportion of native biomass within the plot area. For example, a value of 51 native biomasses in a plot with 100 total biomasses would score 0.51 (51%) for this indicator. This value also indicates that 0.49(49%) remaining biomass is exotic.

Plot O26 was not included in this indicator analysis as there was no 10 x10m plot data in the T1 recording. After calculating naturalness (biomass) values for each plot measure, individual plot values were then averaged by wetland type and measurement cycles.

Naturalness (biomass) indicator values ranged from 0 (one measure) to 1 (5 measures) across all plots, with an average value of 0.68 a median of 0.78. The plot with the lowest biomass score was the baseline measure of J24, a narrow 'gully-bottom' wetland on farmlands in the Waitakere foothills that sits within the Auckland urban area. It had a Naturalness (biomass) score of 0.006 for the re-measure, indicative of its highly modified character. Indigenous plants comprised 100% in the five measures (across four plots) with the highest biomass score (i.e., 1). All these plots were in coastal wetlands ecosystems, often with a significant saline influence (saltmarsh plants and mangroves present.)

Table 12 presents a summary of the Naturalness(biomass) proportionate values for 10m x 10m wetland plots, sorted by wetland type. There was significant difference in indicator values between wetland types for baseline measures (f value = 3.51, n = 31, Significance < 0.05) (Figure 5). Post hoc analyses revealed that the naturalness (biomass) proportionate values in Coastal Wetlands-Natural was significantly higher than Freshwater Wetland- Restored.

Coastal induced wetlands have particularly low values on average, less than 50% of plant biomass in these systems comprises native species. In contrast, Coastal natural wetland plots, have high indicator scores. On average, that 90% of the total biomass was native species within the baseline(T0) recording and plots in these wetlands. It also retained their high native biomass in the five-year re-measures. In contrast to the baseline measures, there were no significant differences in Naturalness (biomass) indicator values between wetland types for plot re-measures (f value = 2.44, n = 31, Significance > 0.05) (Figure 5)

There was a strong correlation between Naturalness (biomass) index values between the two measurement cycles. Across all plots, a paired sample t-test for differences in mean showed no significant differences between the baseline and re-measures (t value = 1.64, n=31, Significance > 0.05). However, there is some suggestion of change in Naturalness (biomass) indicator values for FW restored wetland plots, which showed an increase of 16% over the 5-year period. This is supported by the wide variation in indicator values between different plots, as the difference was significant (t value = 2.72, n = 10, Significance <0.05)

Table 13 is the summary of the 10 x 10m plots for Naturalness(biomass) proportionate values in the KOH datasets. Unfortunately, there was a large decrease in native species biomass in KOHREP5, which had decreased by an astonishing 53%, which may indicate that the plot area was under significant stress or factors that caused the large proliferation of the exotic species after the 9-year period. Despite the difference in naturalness (biomass) in the averaged KOH plots in the baseline (0.50) and 9- year re-measure (0.35), it was found not to be significant (t= 1.18, n= 4, significance > 0.05)

Table 12: Average Naturalness(biomass) proportion values change for 10m x 10m Auckland urban wetland ecosystems (2010 -2019). Data is presented by wetland type.

INDICATOR 3 – Naturalness (Biomass)	T0 (Baseline)	STDev	STDError	T1 (+5 years)	STDEV	STDError
All plots	0.70	0.31	0.06	0.75	0.30	0.05
Coastal wetlands induced	0.51	0.24	0.12	0.45	0.36	0.18
Coastal wetlands natural	0.90	0.17	0.05	0.89	0.13	0.04
FW natural	0.76	0.37	0.14	0.78	0.35	0.13
FW restored	0.54	0.31	0.10	0.70	0.32	0.10

Table 13: Average Naturalness(biomass) proportion values for 10m x 10m Kohuora park wetland ecosystem (2013 – 2022)

INDICATOR 3 – Naturalness (Biomass)	T0 (Baseline)	STDev	STDError	T2 (+9 years)	STDev	STDError
All plots	0.50	0.31	0.15	0.35	0.24	0.12
KOHREP2	0.51			0.57		
KOHREP3	0.09			0.02		
KOHREP4	0.57			0.51		
KOHREP5	0.84			0.31		

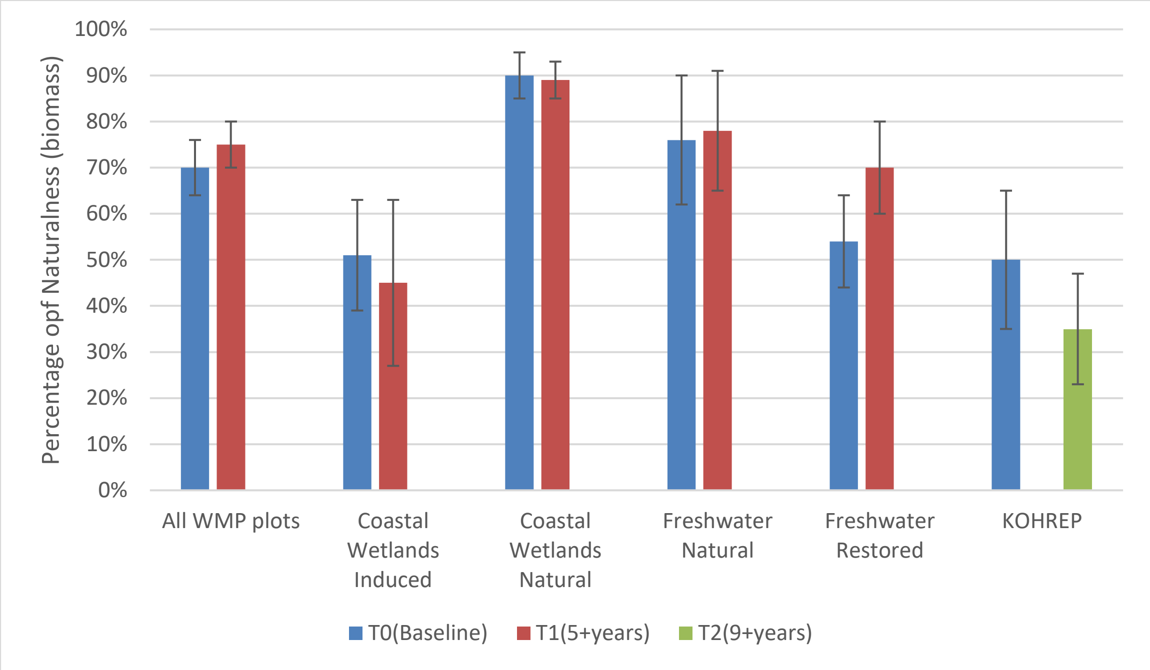

Figure 5: Percentage proportions of Naturalness(biomass) for 10m x 10m Auckland urban wetland ecosystems (2010 -2019) and Kohuora Park ecosystem (2013 – 2022). Data is presented by wetland type and measures

Indicator 4: Shannon diversity

Indicator 4 uses the Shannon diversity index. This index asses the evenness and abundance of species in relation to their dominance. In this indicator, the biomass surrogate was used to form the index values. Figure 6 presents the average Shannon Index values by wetland type and measurement cycle. Shannon Index values ranged from 0 (O28 baseline measure) to 2.13 (K27 re-measure). These two plots had an almost identical total plant biomass (K27 = 150, O28 = 155) however the distribution of that biomass amongst the plant species within the plots was very different. K27 had a species richness of 45 and comprises a restored raupo dominated (34% of biomass) swamp wetland with a high diversity of smaller stature native and exotic plants scattered throughout the raupo. O28 is a natural coastal wetland comprising a monoculture of a single plant species, *Bolboschoenus fluviatilis* (purua grass or marsh clubrush).

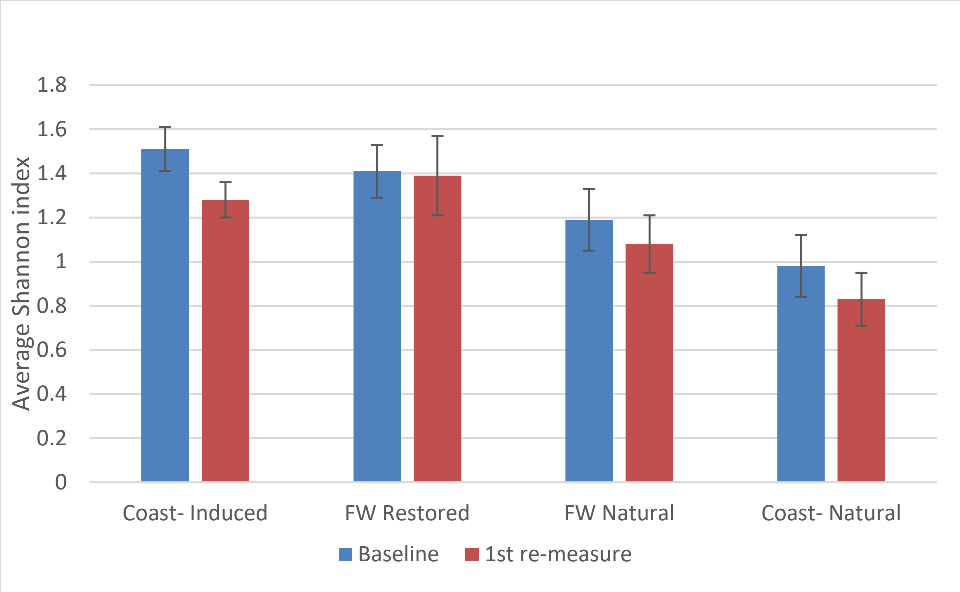

Figure 6: Average Shannon Index values for Auckland Council urban wetland plots by wetland type and measurement cycle. n = 31. Bars are standard errors

There are differences in Shannon Index values between the four wetland types shown in Figure 6. These differences were not significant for the baseline (f value = 2.87, n = 31, Significance > 0.05) but they were significant in the 5-year re-measurement cycles (f value = 3.03, n = 31, Significance <0.05). In general, restored and induced wetland ecosystems had higher SI values, when compared to natural sites. Plots in coastal natural wetland systems in particular have lower species richness, and have more biomass concentrated in a smaller number of plant species, compared with coastal induced and restored wetland systems.

The data in Figure 7 suggest there may have been a reduction in SI values between the baseline and first re-measures. Average SI values are lower for re-measures across all four of the wetland types presented, and SI values had reduced in 19 (61%) of the 31 monitoring plots over the five-year period between the baseline and first re-measure. The average decrease was 0.37 points and the average increase 0.32 points. However, a paired sample t-test showed there was no significant difference between the two measures (t value = 1.41, n = 31, significance > 0.05) (Figure 7).

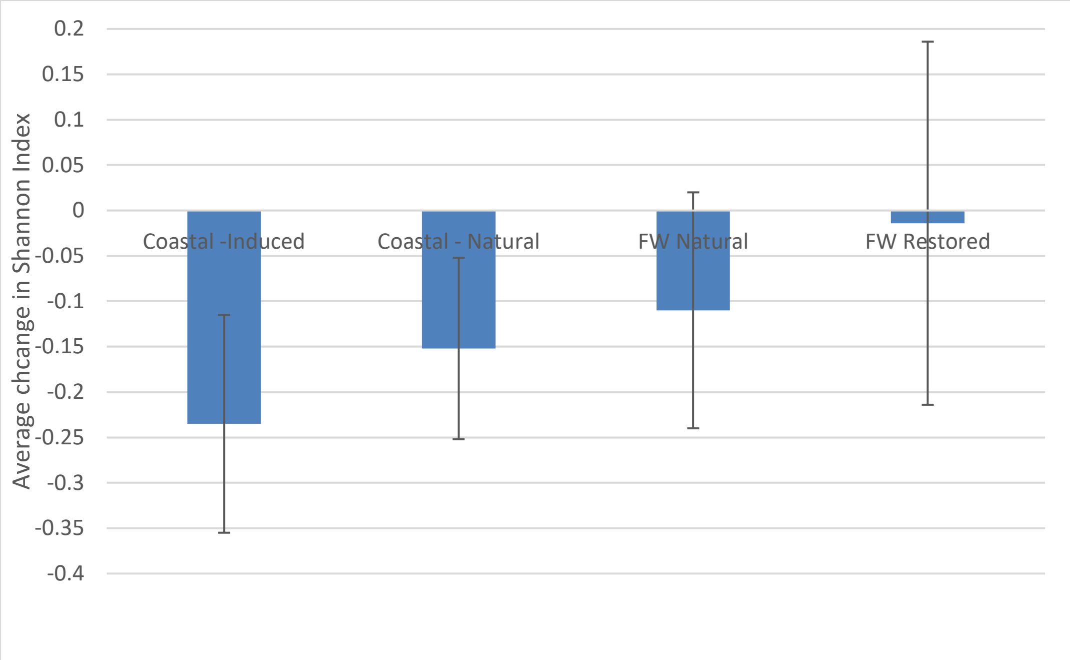

Figure 7: Average change in Shannon Index values between baseline and 1st re-measures in Auckland Council urban wetland plots. Data presented by wetland type. Bars are standard errors.

There was a highly significant (t value 3.52, n = 31, significance < 0.01) but only moderately strong (r = 0.547) correlation of Shannon Index values in wetland plots between baseline and re-measurement cycles. That is, wetland plots with relatively high Shannon Index values in the baseline measurement cycle were also likely to have relatively high values in the re-measurement cycle (and vice versa) (see Figure 8). However, the correlation only explained around one third of the variation in the dataset and this implies that there are range of other factors driving changes in SI values between the five-year measurement cycles.

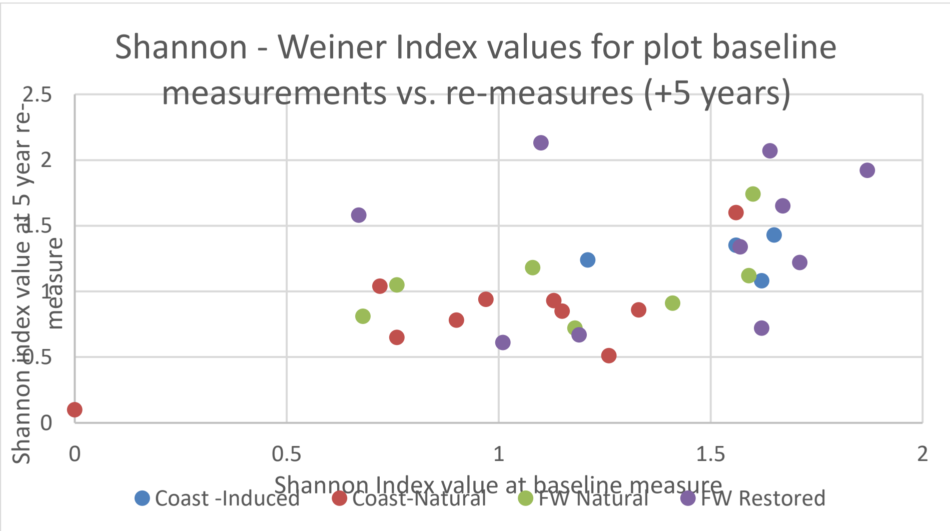

Figure 8: Baseline Shannon Index values vs. re-measure Shannon Index values (5-year rotation) for Auckland Council urban wetland monitoring plots. Data grouped by wetland type. n = 31

Indicator 5: Weed Dominance

The purpose of this indicator is to, in conjunction with indicator 3, -highlight the relative importance of different groupings of plants (i.e., natives vs weedy species) in their contribution to the total biomass of the sampled wetland ecosystems. While indicator 3 is focused upon the Native biomass within the plots, indicator 5 is used to help identify the proportion of harmful, invasive species that are present within the plots.

For this indicator, weed species biomass is incorporated alongside total biomass, which was collected within the 10m x 10m plots. The method used to calculate indicator values was almost identical to the proportional approach outlined for indicator 3. Biomass surrogate (i.e., plant % cover x plant height (m)) values were calculated for individual plant species and then converted into biomass proportions (Weeds biomass/ Total biomass). Average Weed Dominance values for different wetland types were calculated and these are presented in Tables 14 & 15. These tables also include standard deviation (STDEV) and standard error.

Note that the 'direction' of this indicator is different than those presented above. High values on indicators 1 -3 can, in general terms, be regarded as a 'good' score and low values a 'bad' score. The situation for Weed biomass (indicator 5) is reversed. High scores on this indicator are unambiguously bad as they represent an increasing dominance in biomass weedy plants within the wetland plots.

Table 14 shows the average proportion of weeds biomass against the total biomass of each wetland type within the urban wetland plots. There are no significant differences in the indicator value between plots in different wetland types as in both the baseline (f value= 2.75, n = 31, Significance > 0.05) and the five-year re-measures (f value = 2.29, n = 31, Significance >0.05). Coastal Wetlands-induced, have the largest average weed dominance proportion (0.48 or 48% for baseline measures) within their plots. And this increased to 0.52 (52%) following the 5-year re-measures. The wetland type with the lowest weed dominance plot would be the Coastal wetlands -natural with a proportion of 0.10(10%).

Across all wetland types there was no significance difference in the proportion of weedy biomass over the five- year period between the two plot measurements (t stat =0.49, n =31, significance >0.05). The largest change over five years was within plots in the 'Freshwater restored' wetland type. These plots showed a 6% decrease in weed dominance; however, this difference was not significant (t stat = 0.43, n=10, significance >0.05)

Table 15 presents the average weed dominance indicator values for within the Kohuora Park plots. These results show that there is a relatively high dominance of weed species at Kohuora; weeds comprise an average of 55% of wetland biomass in Kohuora plots compared to 25% across all other sites and measures. The data also suggests increasing weed dominance in parts of the Kohuora wetland. KOHREP3 has a very high weed biomass proportion (0.91or 91%), furthermore increasing by 7% over the 9 years between plot measures. In addition, KOHREP 5 showed a very large increase in weed domination as the baseline recording was 8% dominance, which increased to 69% over the 9-year span (61% increase). Overall, the average of the total KOH plots showed a 21% increase of weed dominance between the baseline recording and the 9-year span for the entire KOH plot readings. However, due to the small sample size and variation within plots no significant differences were detected between the two measurements (t value = 1.49, n=4, Significance >0.05)

Table 14: Average Weed dominance proportions in the 10m x 10m plots of Auckland urban wetland ecosystems (2010 - 2019). Data is presented by wetland type.

INDICATOR 5 – Weed Dominance	T0 (Baseline)	STDEV	Std Error	T1 (+5 years)	STDEV	Std Error
All plots (n =31)	0.25	0.28	0.05	0.24	0.29	0.05
Coastal wetlands induced (n =4)	0.48	0.24	0.12	0.52	0.34	0.17
Coastal wetlands natural (n = 10)	0.10	0.17	0.05	0.10	0.13	0.04
FW natural (n = 7)	0.23	0.36	0.14	0.20	0.36	0.14
FW restored (n = 10)	0.34	0.24	0.08	0.28	0.30	0.10

Table 15: Average Weed dominance proportions in the 10m x 10m plots of Kohuora park wetland ecosystem (2013 – 2022)

INDICATOR 5 – Weed Dominance	T0 (Baseline)	STDEV	Std Error	T2 (+9 years)	STDEV	Std Error
All plots (n = 4)	0.44	0.35	0.17	0.65	0.24	0.12
KOHREP2	0.45			0.43		
KOHREP3	0.91			0.98		
KOHREP4	0.33			0.49		
KOHREP5	0.08			0.69		

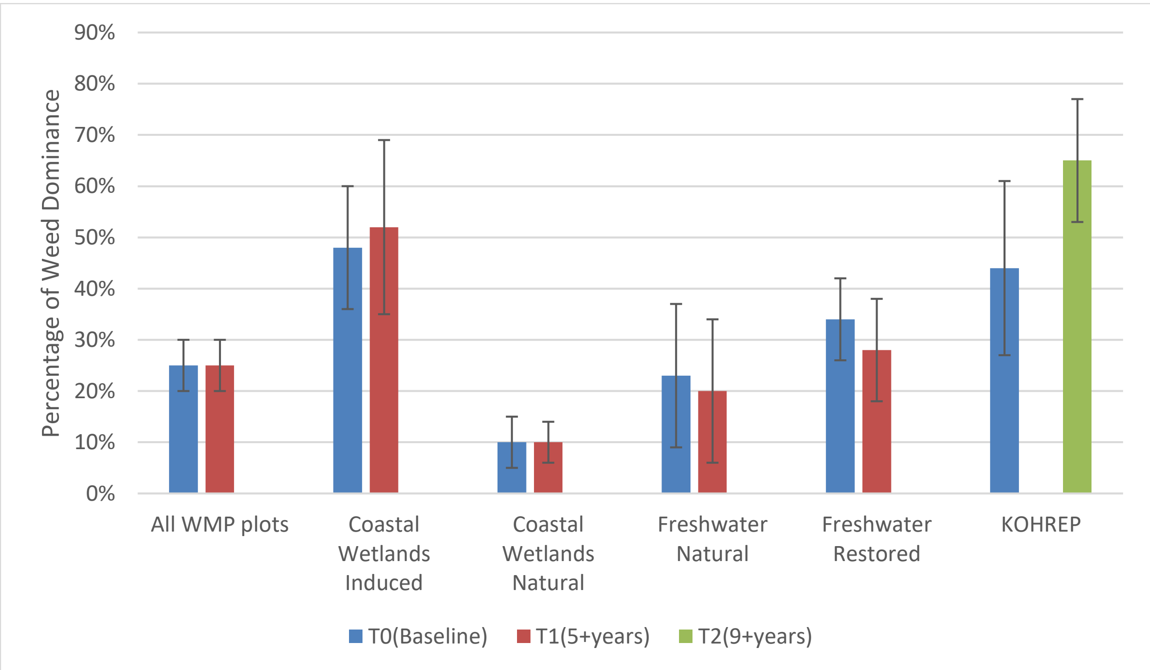

Figure 9: Percentage proportions of Weed Dominance for 10m x 10m plots in the Auckland urban wetland ecosystems (2010 -2019) and Kohuora Park ecosystem (2013 – 2022). Data is presented by wetland type and measures.

Indicator 6: Proportion of dryland plants

Dryland plants refer to a category of plant species that have traits and adaptations towards dryland or terrestrial soils and substrates. This means that the sampled wetlands current vegetation, substrate and hydro systems/ hydrology would be adversely affect by proliferation of dryland plants throughout the wetland ecosystem. The displacement of obligate and facultative wetland plants with dryland plant species may ultimately result in the complete replacement of a wetland ecosystem with a dryland one.

The lack of dryland plants may indicate robustness within the measured wetlands ecosystems. That is, it shows that wetlands in these locations are resilient against the incursions of dryland plants and are relatively more 'healthy'.

Like indicator 5, Indicator 6 is based on the relative biomass estimates recorded within 10m x 10m plots. However, indicator 6 used the relative biomass of wetlands and dryland plants, instead of weedy plant biomass. The indicator value was calculated as Dryland plants biomass/ Total biomass. The plots were then separated into their respective wetland types and average values for different types & time periods calculated. These data are presented in the tables below alongside their standard deviation and errors, which were used to draw the charts (Figure 10)

Table 16 shows the proportionate levels of dryland plant biomass within each of the different urban wetland types measured. Average values are also plotted in Figure 10. Differences between the various wetland types are evident in Figure 10, however, the difference within wetland class variation in dryland biomass proportion is very high. This meant no significance differences were detected in either the baseline (f value = 0.97, n = 31 Significance > 0.05) or five-year remeasures (f value = 0.91, n = 31, Significance > 0.05).

The largest proportion of dryland plants is within the Coastal Wetlands – Induced in the T1 re-measurement (average 32%). The Coastal wetland- Induced plots also have the largest increase in average dryland biomass proportion after the 5-year span (190%) which may indicate a change in the terrestrial environment of the wetlands. However, due to the small sample size within this wetland (n = 4) and high variation in the response of individual plots over the five-year period, this increase was not significantly significant (t value = 1.48, n = 4, Significance > 0.05)

The lowest average dryland biomass proportion was recorded in Coastal wetlands -Natural, which had a value of 9% in the baseline recording and 8% in the five-year remeasures. This result indicates the plots within these wetland types are robust and relatively resistant to dryland plant influence / invasion – although this is based on a relatively short time period (10 years) and it is unclear if this situation will continue into the future.

Freshwater restored wetlands had the highest decrease of dryland biomass between baseline and five-year remeasures of plots (average 8% decrease). However, across all plots, no significant differences in dryland plant biomass were detected (t value = 0.27, n =31, Significance >0.05). Plots which recorded a decrease in dryland plant biomass (n =16) were matched by those recorded in increase or remained static (n =15).

The average dryland plant biomass of Kohuora park plots is presented in Table 17 and Figure 10. These data showed an overall increase of dryland plant proportions over the 9-year period, increasing by 14%. However, this difference was not significant (t value = 1.14, n = 4, Significance >0.05). KOHREP 5 plot recorded a large increase of dryland plant proportions from 9% to 63% (600% increase). This was the result of a large increase in the biomass of the two species: Japanese honeysuckle (250% biomass increase) and blackberry (8,000% biomass increase). KOHREP 4 was the only plot at Kohuora to record a decrease in dryland biomass over the nine-year period between measures (5% decrease). In stark contrast to the other three Kohuora plots, KOHREP 3 had a very low dryland biomass proportion (0.3%) which had increased to 5% in the nine-year remeasure.

Table 16: Change in the average proportion of dryland plant species for Auckland's urban wetland ecosystems (2010 -2019). Data presented by wetland type

INDICATOR 6 –Dryland Plant Proportions	T0 (Baseline)	STDEV	Std Error	T1 (+5 years)	STDEV	Std Error
All plots (n=31)	0.18	0.25	0.04	0.17	0.26	0.05
Coastal wetlands induced (n = 4)	0.11	0.06	0.03	0.32	0.34	0.17
Coastal wetlands natural (n = 10)	0.09	0.22	0.07	0.08	0.20	0.06
FW natural (n = 7)	0.25	0.26	0.10	0.21	0.27	0.10
FW restored (n = 10)	0.24	0.29	0.09	0.16	0.26	0.08

Table 17: Change in average proportion of dryland plant species for Kohuora park wetland ecosystem (2013 – 2022)

INDICATOR 6 – Dryland Plant Proportions	T0 (Baseline)	STDEV	Std Error	T2 (+9 years)	STDEV	Std Error
All plots (n =4)	0.11	0.12	0.06	0.26	0.25	0.13
KOHREP2	0.09			0.15		
KOHREP3	0.003			0.05		
KOHREP4	0.28			0.23		
KOHREP5	0.09			0.63		

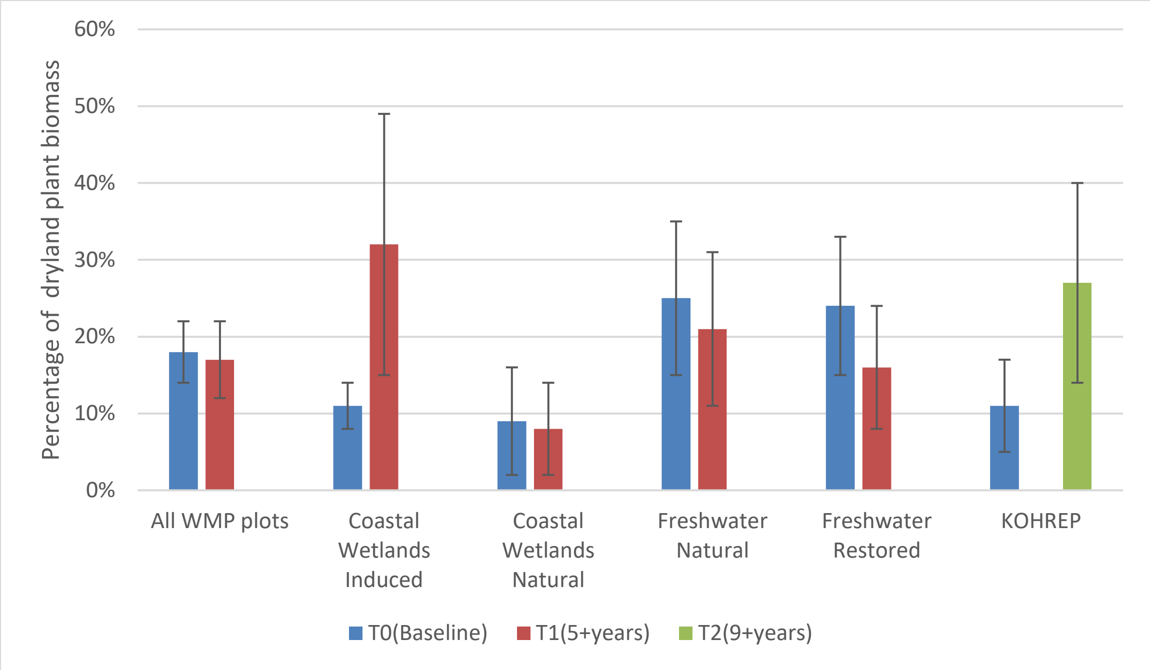

Figure 10: Percentage change of average proportions of dryland plant species for Auckland Council urban wetland ecosystems (2010 – 2019) and Kohuora Park wetland ecosystem (2013 – 2022). Data is presented by wetland type and measures.

Indicator 7: Dieback of all plants

Table 18 present the proportion of dead plant biomass of all urban wetland plots in the WMP dataset, separated into their exotic and native categories. Noted, that despite the low values for some of the wetland types in Table 18, the data is in proportion. For example, 0.0005 would translate into 0.05% of the total biomass comprising dead plant tissue. Coastal wetlands- natural and Freshwater-Natural plots have a higher dead native biomass for the baseline recording (of 11.3% and 10.1% respectively). However, there were no statistically significant differences in the proportion of dead biomass between wetland types for native or exotic plants in baseline measures (native plants * f value = 0.57, n = 31, Significance > 0.05; exotic plants* f value = 0.69, n = 31, Significance > 0.05) or five year remeasures (native *plants f value = 1.32, n = 31, Significance > 0.05; exotic plants *f value = 1.51, n = 31, Significance > 0.05).

There were no significant changes in the proportion of dead native biomass (t value = 0.18, n = 31, Significance > 0.05) or dead exotic biomass (t value = 0.96, n = 31, Significance > 0.05) in the five-year period between the two plots sampling events.

There are some obvious differences in dead biomass between native and exotic species (Table 17 and Figure 11). Average dead exotic biomass is less than average dead native biomass within this dataset for both the baseline (3.7% vs. 7.8% respectively) and remeasure (1.9% vs. 8.5% respectively) data. These differences were not significant for the baseline measures (t value = 1.17, n = 31, Significance > 0.05) however there was a significant difference between native and exotic dead biomass for the plot remeasures (t value = 3.27, n = 31, Significance < 0.01).

Table 19 presents average dead plant biomass values for the replicate plots in Kohuora Park. KOHREP 4 &5 have a high dead native proportion (14% and 29.4%) in the baseline recording. This mainly due to the high biomass of *Typha orientalis* and *Carex Secta* (128.5 and 67.5 biomass respectively). However, there was a sharp decrease in dead native plant biomass in KOHREP 5 in the T2 recording, decreasing by 25.9%. Comparing the different recordings of T0 and T2, it is clear that there is a decrease in dead native plant biomass over the 9-year span. KOHREP 3 showed 0 dead biomass detected within the plot in the baseline and T2 reading.

Table 18: Change in average proportion of dead plant biomass for Auckland's urban wetland ecosystems (2010 – 2019). Data presented by wetland type.

INDICATOR 7 – Dieback of all plants	T0 (Baseline)		T1 (+5 years)	
	Exotic	Native	Exotic	Native
All plots (n =31)	0.037	0.078	0.019	0.085
Coastal Wetlands induced (n =4)	0.029	0.065	0.053	0.086
Coastal Wetlands natural (n = 10)	0.003	0.113	0.005	0.124
FW natural (n = 7)	0.019	0.101	0.0005	0.027
FW restored (n = 10)	0.087	0.033	0.032	0.082

Table 19: Change in average proportion of dead plant biomass for Kohuora Park wetland ecosystem (2013 – 2022).

INDICATOR 7 – Dieback of all plants	T0 (Baseline)		T2 (+9 years)	
	Exotic	Native	Exotic	Native
All plots (n = 4)	0.002	0.125	0.003	0.037
KOHREP2	0.007	0.067	0.006	0.015
KOHREP3	0	0	0	0
KOHREP4	0	0.140	0	0.114
KOHREP5	0.003	0.294	0.007	0.035

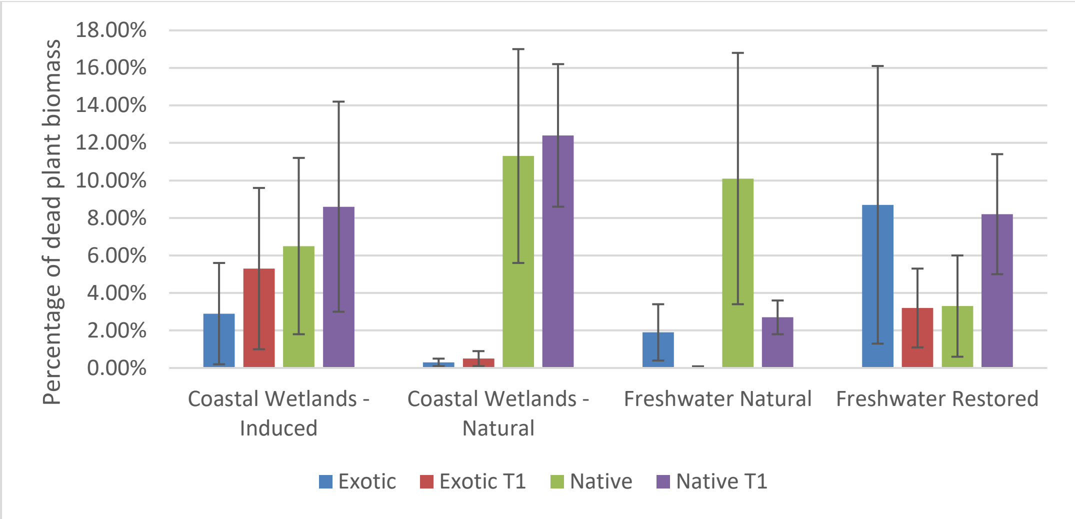

Figure 11: Percentage change of average proportions of dead plant biomass for Auckland Council urban wetland ecosystems (2010 – 2019). Data is presented by wetland type

Discussion

Wetland Indicators

There are clear differences in the values of the six indicators between the four wetland types evaluated as part of this dissertation (Table 20 & 21). Each indicator represented a different aspect of 'wetland health'. Collectively these different indicators are useful for the evaluation of restoration progress in specific sites and/ or progress towards achievement of the 'wetland protection and enhancement' policy goals of regional councils, NGO's and central government agencies . Using these indicators in conjunction with each other provided further insight towards each respective wetland types.

Table 20: Average values of Indicators 1 -6 for Auckland urban wetlands in the baseline measurement (n = 31), Data is presented by wetland types and Indicators.

	Natural Wetlands		Constructed or induced wetlands	
By Average;	Coast Natural (n = 10)	FW Natural (n =7)	FW Restored (n= 10)	Coast Induced (n =4)
Species Richness	13.5	16.57	23.3	21.5
Naturalness (Richness)	2.67	2.35	0.54	0.38
Naturalness (biomass)	0.90	0.76	0.54	0.51
Shannon Diversity Index	0.98	1.19	1.41	1.51
Weed Dominance	0.10	0.23	0.34	0.48
Dryland plant proportion	0.09	0.25	0.24	0.11

Table 21: Average vales of Indicator 1-6 for Auckland urban wetlands in the 5-year remeasurement (n =31). Data is presented by wetland types and Indicators

	Natural Wetlands		Constructed or induced wetlands	
By Average;	Coast Natural (n = 10)	FW Natural (n =7)	FW Restored (n= 10)	Coast Induced (n =4)
Species Richness	14	19.71	23.6	21.75
Naturalness (Richness)	1.83	1.62	0.60	0.52
Naturalness (biomass)	0.89	0.78	0.70	0.45
Shannon Diversity Index	0.83	1.08	1.39	1.28
Weed Dominance	0.10	0.20	0.28	0.52
Dryland plant proportion	0.08	0.21	0.16	0.32

Table 22: Average values for Indicator 1-6 for the Kohuora Park replicates. Data is presented by the measurements and indicators.

	Kohuora Park Replicates (10m x10m, n = 4)	
By Average;	Baseline	9- year re-measure
Species Richness	19.50	14.0
Naturalness (Richness)	1.02	0.82
Naturalness (biomass)	0.50	0.35
Shannon Diversity Index	1.60	1.45
Weed Dominance	0.44	0.65
Dryland plant proportion	0.11	0.26

INDICATOR 1

Indicator 1 is species richness. Species and functional group richness or diversity is a widely used measure of the quality of habitat, with more diverse ecosystems often being seen as 'better' than less diverse ones (Hooper & Vitousek, 1997; Fridley, 2003; Cadotte, Carscadden, & Mirotchnick, 2011). This is because more diverse communities have been shown to have higher and more temporally stable ecosystem functioning, and consistently higher productivity than less diverse ones (Allan, et al., 2011). Ecosystems with a high diversity of native plant species also provide habitat for a wider range of native plants, and potentially a greater diversity of indigenous invertebrate and vertebrate animal species that live off this more diverse and productive plant resource base, as productivity increases with diversity (Rujiven & Berendse, 2005).

Wetlands are a unique ecosystem that often acts as a transitional zone between terrestrial and aquatic ecosystems, known as ecotones (Hatvany, 2009). This mixture of terrestrial and aquatic habitats creates a rich biodiversity and unique habitats for a variety of flora and fauna. However, due to hydrological fluctuation of some wetlands, the soil composition, water levels and hydro systems typically create hypoxic conditions (Luo, Jiang, Li, & Yu, 2016). This leads towards the proliferation of specific plant species that have acclimatized or adapted to various different 'hydrological niches', further increasing species richness and productivity (Goswami & Mukhopadhyay, 2002).

Changes in wetland hydrological regime (i.e. wetter, drier and / or changes in temporal distribution of water) may influence the balance between wetland plants, skewing towards more efficient competitors and stimulating their growth and abundance (Meyerson, Chambers, & Saltonstall, 1999) due to the sensitivity of the biota to these changes (Mitsch & Gosselink, 2015).

Reduction in species diversity may inversely effects productivity in some wetland communities, as these adaptations may create plant communities that have high productivity without reliance on ecosystem mechanisms (i.e., competition) (Waide, et al., 1999). In terms of productivity, each wetlands type has its differences. Some coastal and inland wetlands, such as mangrove swamps, raupo (*Typha orientalis*) reedland and purua (*Bolboschoenus fluviatilis*) grassland have very low species richness but are still amongst the most productive ecosystems in New Zealand and globally (Waide, et al., 1999; Brun, et al., 2019). This is despite their flooding, low oxygen soil levels and natural salinity. One such coastal wetlands that has low species diversity, but high productivity would be mangroves swamps (Ochoa-Gomez, et al., 2019).

Notwithstanding the caveats outlined above, species richness is a potential indicator for monitoring changes in the 'environmental health' of the wetland ecosystem. It is important to know if the 'species richness' of Auckland's wetland ecosystems is changing over time, how dramatic these changes are, and if they are regional in nature or confined to specific wetland types or locations.

INDICATOR 2

Indicator 2 is used to provide further insight towards 'naturalness' using values that show the balance between native and exotic plant species. Where there are large numbers of exotic plant species relative to natives (lower naturalness score), exotic plants are probably occupying a greater number of niches and excluding more native plants. A dominance of exotic plants also implies a greater vulnerability to future weed stress as a high native biodiversity acts a barrier towards invasive species (Kennedy, et al., 2002).

INDICATOR 3

Biomass can be used a measure to determine the degree of species dominance within the ecosystem. While indicator 1 and 2 show the species richness and balance between native and exotic species, it lacks the detail on the relative biomass of the exotic vs native plants within the sampled wetlands. By estimating biomass of the plants in 10m x 10m plots, we are able to assess differences in species community structure (Guo & Rundel, 1997). Biomass is also used to reflect the levels of nutrients and productivity within the ecosystem as plant biomass is a measure of energy storage in plants (Fan, et al., 2021). It also helps identify dominant plant species and the interspecific competition within the ecosystem (Cheng, Zhang, Zhao, & Gadow, 2018).

In indicator 3, a biomass surrogate value (i.e., estimate is calculated by using cover percentages and height tiers. Using this biomass surrogate allowed for analysis the levels of plant biomass proportions across the ecosystem and gauge the levels of biomass for dominant species within each plot. However, the biomass surrogate relies solely on visual estimates of the cover percentages and height tiers, thus more vulnerable to observer bias. Using cover percentages over values high density plant species that have large leaf spans or branches that stretch across the plot. As we use height tiers as the second calculation for biomass, a large series of leaves or branches widely stretching over the plot creates a large biomass value without truly taking into account the density of the plant species. This biomass surrogate favours horizontal growing plant species as a higher cover percentage would drastically increase the biomass value.

INDICATOR 4

Species richness takes no account of the relative dominance or biomass of individual plant species within the sample plots. A plant species that was abundant across the whole plot, extending into multiple vegetation tiers, is recorded the same way as the single occurrence of a tiny seedling. The Shannon–Wiener diversity index (Shannon Index or SI) is a popular metric that has been used to calculate the species diversity of a wide range of different ecosystem types (Spellerberg & Fedor, 2003; Awal & Svozil, 2010; Hong, Liu, Shi, & Zhang, 2012). The Shannon Index takes into account the number of species within a plot (i.e., species richness data presented in Indicator 1) and their relative abundance (evenness).

By itself, the Shannon diversity index values are difficult to interpret and has to be used alongside other indicators or measurements, such as species richness or biomass. Taking into account of Indicator 1 and 3 allows further insight between species richness and biomass as a reduction in Shannon index in a wetland may indicate a change in species richness or an increase in concentration of biomass into individuals.

INDICATOR 5

Using weed dominance as an indicator provides key information about the ecological integrity of the wetland ecosystems the data was collected from. Not all exotic plant species are considered weeds. Ecological weed species have invasive properties which impact the structure and function of the ecosystems in which they are found (Simberloff, et al., 2013; Ehrenfeld, 2010). In the case of wetland ecosystems, ecological weed species have been shown to displace native plants, disrupt natural hydrological function and alter nutrient cycles (Zedler & Kercher, 2004). Not all exotic species are considered weeds as their traits do not risk or hinder the growth of native plant species that are present.

INDICATOR 6

Dryland plants refer to a category of plant species that have traits and adaptations towards dryland or terrestrial soils and substrates. When it is functioning 'normally', a wetlands substrate and hydro systems/ hydrology would adversely affect the growth and proliferation of dryland plants within the wetland ecosystem as their adaptations are not suitable to sustain themselves for long periods of time. Increasing dryland plants in regard as a negative result as it is altering this natural functioning.

Using the proportion of dryland plants as an indicator helps provide further insight about the hydrological status of the wetlands and influence of climate change (Sandi, et al., 2020). As wetlands are known to be the transitional zone that merges aquatic and terrestrial environments, also known as ecotones (Hatvany, 2009), the indication of a high dryland plant proportion may imply that the substrate and hydro system balance between terrestrial and aquatic environments have changed. The change of environment towards favouring the terrestrial environment may provide advantages towards the proliferation of dryland plants and thus reducing the populations of wetland plants. The change towards the development of the dryland environment also shows the failures of wetland plants species to support and maintain their unique hydro system and substrates. Furthermore, this affects their general growth and ability to compete, as native species competition against invasive dryland plant species are strongly inhibited in dry conditions (Price, Berney, Ryder, Whalley, & Gross, 2011). The change in dryland plant proportions may also be due to surrounding environmental factors such as drought or 'drying up' of wetland substrate, or human disturbance. Scenarios that cause a temporary or permanent 'drying up' of the wetland substrate, would cause dryland plant invasion till the next fluctuation of water flow (Sandi, et al., 2020)

INDICATOR 7

Dead biomass can be used as an indicator within a variety of ecosystems, some mainly towards understanding the extent of nutrient resorption proficiency alongside acting as indicator towards the ecosystem capacity for energy flow and biogeochemical cycling. However, within this study, dead biomass is used as an indicator to determine the levels of dieback of exotic and native plant species within the wetland's ecosystem. This allows us to examine any significant death of native or exotic plants within that plot.

However, the results presented in my analysis suggest that Indicator 7 (Dieback of all plants) is unsuitable as a measure of restoration progress or environmental health of wetland ecosystems. However, this indicator can be used as a more general measure of dead biomass within the sampled wetlands. Dead biomass is mainly used in analysis of nutrient recycling, retention within the ecosystem and providing further insight towards soil nutrient status (Carneiro, Fabião, Serrao, & Madeira, 2009). Initially, it was thought that a dead biomass indicator would provide insights about the healthiness of the ecosystem, as less native dead biomass would equate to a sustaining ecosystem while a high native dead biomass level would indicate that the ecosystem was deteriorating. The main reason that dead tissue proved to be unreliable as an indicator of health was the fact that several dominant native wetland plant species are deciduous, and these species skewed the biomass measurement (towards 'bad' values) with their large cover proportion. These specific native plant species are *Bolboschoenus, Bolboschoenus fluviatilis and Typha orientalis (*raupō), which all had large biomass recordings (<100) in many of the plots where they occurred due to their cover/ spread across the plots and their relatively large stature.

Moreover, the results of this indicator showed some unexplainable inconsistencies such as the KOHREP3 which had 0 dead biomass readings for exotic and native within the baseline readings and the T2 readings. In addition, analysis of observer bias in the field has shown that dead biomass estimations can vary widely between different botanists (unpublished Auckland Council data), and this can have a large impact on the value of this indicator.

Wetland types

Within the **Coastal Wetlands – Induced** are wetlands that have been highly affected by the consequences of human activity, as their ecosystem formation is based upon the urban development of local landscapes such as culvert, drainage channels, and increased sedimentation due to forestry (Ministry for the Environment, Defining 'natural wetlands' and 'natural inland wetlands', 2021). Therefore, it is to no surprise that this wetland type has highly favourable conditions for the proliferation of exotic species, encouraging weed growth and invasions.

This is supported by the various indicator values for the 'coastal wetlands- induced' wetland types. Indicator 1 showed that it had the highest average of exotic plant species richness of 15.75 in the baseline measure across the wetland types, and 14.25 exotic species richness in the baseline measures and five-year remeasure, which is the second highest average among the wetland types. It also showed the lowest native species richness in both measures (5.75 & 7.5). Indicator 2 – Naturalness showed that the indicator levels used to determine the degree of naturalness (native vs exotic) was the lowest among all the other wetland types and plot types. This high degree of exotic plant species proliferation and harmful weeds can be further supported via indicator 3 and 4. Indicator 3 also displayed this wetland type to be the lowest in native biomass (51% and 45%) while Indicator 5 showed the highest biomass proportion of weed species (48% and 52%) in the baseline recording and T1. Indicator 6 showed a very large increase of 190% of dryland plant proportions in the 5 -year remeasure (from 0.11 to 3.4) but was not significant.

Overall, based on the indicator results presented in this dissertation, the health of the induced coastal wetlands can be seen to be 'unhealthy'. This is supported by the very low native plant species richness and 'naturalness' values. Results from indicator 3 and 4 showed that the overall biomass of native species have deteriorated while the majority of the biomass belong to exotic species in both measures. This is reinforced by the dryland proportions in indicator 6, which was the highest across all wetland types. However, the issue with the Coastal wetlands induced plot data is the small sample size of four plots. This alongside high variation created negative significance tests for all indicators for induced coastal wetlands.

Coastal Wetlands – Natural, are the opposites of induced. They represent coastal wetlands that were created naturally. Natural Coastal wetlands are known to be the most productive wetland ecosystems as they consist of estuaries, which have a mixture of freshwater and saltwater sources. The drainage of freshwater from rivers into the sea creates high levels of suspended sediment near the mouth of the rivers, retaining an abundant amount of nutrients from the land runoff (Elliott & Whitfield, 2011). Its interaction with the tidal system provides a mixing action, driving production further (Monsen, Cloern, Lucas, & Monismith, 2002; Brauwere, Byre, Blaise, & Deleersnijder, 2011). Their role as a freshwater, saltwater ecotone can result in higher biomass and species richness, some of which can be supported from the indicators.

Results from indicator 1 showed that the natural coastal wetlands had the lowest average exotic species richness in both measures (5.4 & 6.5) while having the highest average native plant species in the baseline measurement (8.1). Indicator 2 supports the high native species richness as its 'Naturalness' values are the highest across all of the wetland types in both baseline (2.67) and five-year re-measure (1.83). This supports the species richness in indicator 1, as native species richness higher than the exotic species richness in both measures. The naturalness (biomass) from indicator 3 also showed the highest levels of 'naturalness' (biomass) in both measures (0.9 or 90% and 0.89 or 89%). This is supported by indicator 5 which showed the lowest weed biomass among the wetland plots (10 %) in both remeasures. Furthermore, the dryland plant biomass proportions in indicator 6 resulted in the lowest biomass measurements in both measures (9% and 8%).

Using the indicators in conjunction with each other, it can be summarised that this wetland type is very 'healthy' within the baseline measurement despite its low average species richness. It is the only wetland type that has a higher native plant species richness over exotic plant species richness across all wetland plots. This is supported by indicator 3,4 & 5, which showed very high native plant biomass values, a very low weed domination and dryland proportions in all measures.

In terms of their origins, **Natural Freshwater Wetlands** are similar to natural coastal wetlands as its their formation is the result of mostly natural processes (i.e., without influence from human interactions). However, freshwater wetlands represent wetlands that are generally inland, and have hydro system properties tying to freshwater sources, such as rivers and lakes (Fergus, Lapierre, Oliver, & Skaff, 2017).

Results from Indicator 1 showed a higher average of exotic plant species richness than the average native plant species richness in both measures within this wetland type. This is supported by Indicator 2 which showed a 'naturalness' value of 2.35 and 1.62 in the baseline and 5- year remeasurement. Indicator 3 showed naturalness (biomass) value of 0.76 in the baseline measurement and 0.78 in the 5-year re-measurement. Indicator 5 showed low levels of weed dominance in both measures (0.23 and 0.20 respectively) The dryland plant proportions (Indicator 6) was the highest among all wetland types in the baseline measurement (0.25) but was second highest in the 5-year remeasure (0.21), beaten by Coastal Wetlands – Induced.

Overall, the 'health' of this ecosystem is questionable as the average exotic plant species richness is higher than the average native species richness, but not overwhelming as Coastal wetlands induced. Indicator 2 'naturalness' values are also relatively high alongside Coastal Wetlands – Natural 'naturalness' values. Using indicator 3 in conjunction with indicator 5 and 5 showed high native plant biomass with low levels of weed species dominance and dryland plant proportions in both measures. This overall shows a 'healthy' ecosystem in terms of high native biomass, despite a higher level of exotics plant species.

Freshwater Wetlands -Restored represent freshwater wetlands that have had direct interaction with human restoration efforts, henceforth the term, restored. These wetlands are a focus on restoration projects as their original wetland size or plot have deteriorated beyond natural recovery, usually because of human urbanization. This means they have required direct human input to re-plant and establish a wetland in these locations. In some cases, more 'wetland type' hydrological regimes have also had to be re-created before planting. These wetlands are usually the focus of multiple policies and restoration projects as an effort to support the ecosystem and prevent further deterioration.

Using the results from Indicators1-7, it is possible gain an understanding of the 'success' of these restoration projects. Indicator 1 showed that this wetland type has the second highest average native plant species richness (7.8) in the baseline measure across all wetland types, while the 5-remeasure has the value of 8.8. The exotic species richness in the baseline measurement is the second highest (15.5) while the 5-year remeasurement has the highest average exotic plant species richness across all wetland types (14.8). This suggests that constructed wetlands are vulnerable to the invasion of exotic plant species. The reason for this is unclear. Perhaps constructed wetlands are more likely to have 'empty niches' that can be exploited by more competitive exotic/ weedy species due to their artificial nature? Another possibility is that the disturbance and alteration of the physical environment that occurred during site preparation and planting has aided the establishment of exotic plants.

Either due to the direct impact of disturbance, or the importation of exotic plant species as part of soil preparation, foreign soil associated with planting pots etc. The relatively high native species richness may be due to an 'artificially high' richness of native plants used in establishing constructed wetlands. However, I present no evidence to confirm this effect, and it is also possible that the higher native plant species could be a natural phenomenon. Indicator 2 showed the lowest 'naturalness' indicator values for both measures (0.56 & 0.60). Indicator 3 however, showed a significant increase in naturalness (biomass) over the 5-year re-measurement, from 0.54 to 0.70. Indicator 5 showed the second highest weed dominance proportions across the wetlands in both measures (0.34 and 0.28 respectively). Indicator 6 results showed that the average proportion of the dryland plant species in the baseline recording was the second highest (0.24) while the 5-year remeasure was the second lowest (0.16) across the four wetland types.

The combination of results from these indicators shows that the restoration progress of these restored freshwater wetlands to be positive despite the lack of significant differences in indicator 1,2, 5 and 6. However, indicator 3 resulted in a significant difference between the baseline and the 5-year remeasure, showing an increase from 0.56 to 0.70 average naturalness(biomass) proportion value. This implies that despite the lack of change in species richness, 'naturalness', weed dominance and dryland plant proportions, increasing native plant biomass indicates some continued growth and re-establishment of native species within the ecosystem.

Kohuora Park

The Kohuora Park Plots are classed as Freshwater Restored wetlands. This site is a constructed wetland that was restored by the Manukau City council in 1995 (Figure 13 -17). Auckland Council took over management of this site in 2010. Several wetland monitoring plots were established as replicates (in 2013) to individually observe and monitor changes in the Kohuora Park wetland systems. Using these data, it is possible to observe the results given by the indicators to assess the state and progress of restoration policies over a 9-year re- measurement, compared to the Auckland urban wetlands plots. This provides insight towards the potential changes over a longer period of monitoring compared to a 5-year re-measurement.

Results from Indicator 1 showed the value of 9.5 & 6.5 for the average native plant species richness and 10 &7.75 for the average exotic species richness in the baseline measurement and 9-year remeasurement respectively. There is a significant decrease in native plant species richness between the baseline measurement and 9-year remeasurement. Indicator 2 showed a decrease in 'naturalness' from 1.02 to 0.82 between the baseline measurement and 9-year remeasurement respectively. However, this difference was not significant. Indicator 3, the naturalness (biomass) showed a decrease in native biomass from 0.50 in the baseline to 0.35 in the 9-year remeasurement, but this was also not significant. Results from Indicator 5 showed very high weed dominance proportions in both baseline measurement (0.44) and 9-year measurement (0.65). There were no significant changes in weed dominance in the 9-year measurement. The dryland plant proportion values in indicator 6 was low in the baseline measure (0.11) but was high in the 9-year remeasure

(0.26). The differences in dryland proportion values was not significant. In indicator 2-5 there was no significant differences in 'naturalness', naturalness(biomass), weed dominance and dryland plant proportions between the baseline measure and 9-year remeasure. This is maybe due to the high variance and low sample sizes of the Kohuora Park plots (n =4).

The high native & exotic plant species richness of the Kohuora Park plots, is similar to that recorded or other wetlands in the 'Freshwater Restored.' Class. The high exotic species richness maybe due to its previous state before restoration efforts as it indicates a low resistance to exotic plant invasion. Some of the replicates may be influenced by surrounding factors. For example, KOHREP4 is significantly easier to access compared to the other KOH plots due to a walkway nearby (see Figure 13) which may indicate that it was more exposed to disturbance or factors that benefit the growth of exotic species.

The restoration progress of this wetland can be inferred, according to the indicators presented in my dissertation to be less successful. There is no significant change in all indicators bar indicator 1 which showed significant decrease in native species richness over the 9-year re-measurement (i.e., a negative effect). This may be due to the domination of a small number of exotic tolerant plant species that would succeed in interspecific competition against native plant species due to environmental constraints and pressures (Zhang, et al., 2020).

Discussion of the Aims of the dissertation

1. What are the most 'useful' environmental indicators for use in monitoring the health of Auckland's wetland ecosystems?

In terms of monitoring the health of Auckland's wetland ecosystems, Indicators 1 and 2 were useful for evaluating the balance of native and exotic species richness among the wetland plots. Indicators 3,4 and 5 provided further insight into coarse scale changes in the abundance of different plant species and species groupings (i.e., native vs exotic vs weeds) by assessing changes in plant biomass and dominance within the ecosystems. While indicator 6 was used as an indicator of robustness towards climate change or changes in the wetland hydrology.

2. What is the most appropriate plot size/ data combination to use in calculating the different environmental indicators?

The Auckland Council urban plots made use of three different plot size configuraitons, all nested within each other. Namely 15m x15m plots(225m^2), 10m x 10m plots(100m^2) and nine 2m x 2m plots(36m^2). However, the 15m x 15m plots and the nine 2m x 2m plots was based on presence / absence of plant species in tiers and no cover or relative dominance information was collected. This meant that they provided no suitable data for creating a biomass surrogate that could be used in indicators 3,4 ,5, 6 and 7. Additionally, size and scale of the 10m x 10m plots were more feasible and reliable to use to record data within the Auckland Council Urban plots. I recommend using the 10m x 10m plot, with biomass data, as the standard plot size for monitoring wetland ecosystems in future analyses.

3. Are there any differences in the plant species richness, diversity and composition of natural vs. constructed/ induced wetlands?

Natural coastal wetlands and freshwater wetlands can be seen to have lower total species richness than the induced coastal wetlands and restored freshwater wetlands. However, this is due to the different traits of these ecosystems. Induced wetlands have a very high exotic species richness but lower native species richness than the natural coastal and freshwater wetlands as their surrounding environment, hydrology and hydrological features are highly beneficial towards the proliferation of exotic species. Restored freshwater wetlands, however, have a higher native species richness than natural coastal and freshwater wetlands as well as a higher exotic species richness than the induced coastal wetlands. This may be due to the methodology and properties of a constructed wetlands as native wetland plants may have been artificially inserted into the wetlands to support and enhance ecosystem services, while promoting future regrowth of native wetland plants. The reason behind the high exotic species richness is unclear, as there are unknown factors that could be the main influence the growth and proliferation of these exotic plant species, such as the exploitation of 'empty niches', increased interspecific competition due to the artificial nature of the constructed wetlands (Zhang, et al., 2020) or the direct impact of disturbances or the importation of exotic plant species during the preparation of soil during wetland construction.

4. Based on the environmental indicators from Aim 1, has there been any significant change in the health of Auckland's urban wetland ecosystems over the 2010 – 2019 period?

The overall change in the health of Auckland Urban wetland ecosystems over the 2010 – 2019 period can be seen to be mostly not significant. Across all plots, a sample t -test for differences in mean was applied to all indicators. Indicator 1 showed no significance differences in native, exotic and total species richness between the baseline measure and 5-year remeasure. Naturalness(biomass) showed no significant differences between the baseline and re- measures in indicator 3. However, there is some indication of change in naturalness(biomass) in freshwater restored wetlands as it showed a significant difference between the baseline and re- measure. Indicator 5 and 6 also showed no significant differences in weed dominance nor dryland plant proportions between the baseline and 5-year remeasure.

5. Are there any differences in wetland health between natural freshwater wetlands, constructed freshwater wetlands, natural coastal wetlands and induced coastal wetlands?

There is a difference between wetland health among the wetland types, as shown above. Natural Coastal wetlands have the healthiest ecosystem based on the indicators. Coastal wetlands induced have the least healthy ecosystems as due to high exotic invasions and high human disturbance. Freshwater natural wetlands are moderately healthy, not to the same level as natural coastal wetlands, as the indicators show that there is a very small improvement in health at face value but was not significant. Freshwater restored wetlands are difficult to compare to the other wetland types in term of healthiness, as plant diversity and abundance in these locations is probably artificially supported by the maintenance and supplementation of native wetland plants, which may have inflated the native species richness. However, using indicator 3 -Naturalness (biomass), the restoration effort towards improving the ecosystem health can be seen to be positive as there is a significant positive growth of native biomass in the re -measure.

Kohuora Park wetlands plots provided some insight towards the potential changes through a 9- year period, as opposed to the 5 -year period in the Auckland Council Wetland plots. However, it must it be noted that the number of replicates used within this study was insufficient as other replicate locations proved to be too difficult to access due surrounding water canals and dense thorny blackberry. The low number of replicates meant that detecting significant differences was less likely, despite the obvious difference in indicator values.

Future study notes

The conclusions that can be drawn from my study are restricted by the number of samples for each wetland type. Some wetland types and locations, such as the Coastal Wetlands -Induced type and the Kohuora Park replicates, had a sample size that was too small to properly determine the significance difference for each indicator. The data measured was also limited to a relatively short timeframe of one 5-year remeasurement cycle, as only ten years of data (2010 -2019) was available for my study, and each measurement cycle occurred takes five years to complete. The measurement methods used for each grid plot mainly used visual confirmation to examine and record the species richness, height, cover percentage and presence in the plot. This subjects the data to observer and observant bias. Future studies should include a review of the methodology used to measure and record the data, maybe analysis on comparison between of this grid measurement to the advantages of the point-intercept method (Nunes, Tapia, Pinho, Correia, & Branquinho, 2014) to reduce observer bias as much as possible

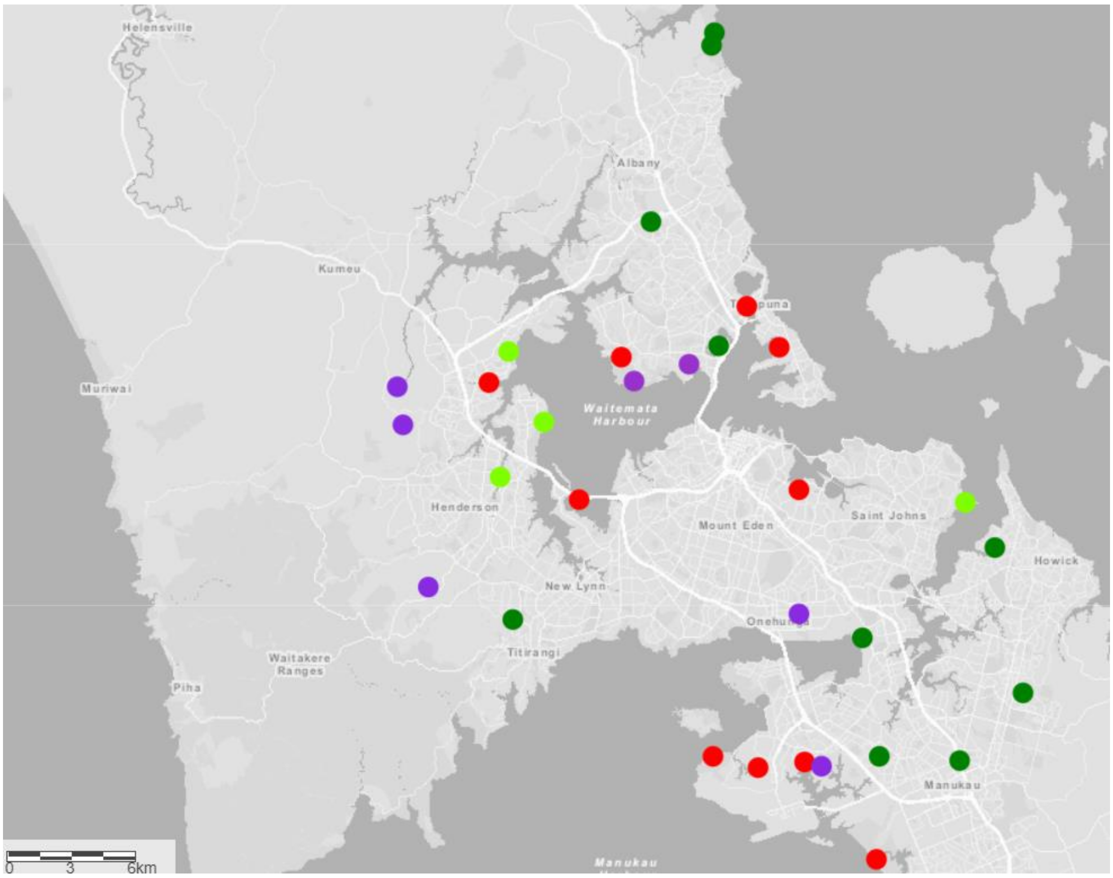

Figure 12:Location of the 31 grid wetland plots used in this study. Plots are coloured by wetland types. Red dots = Coastal – natural wetlands (n = 10). Light green dots = Coastal Induced wetlands (n = 4). Purple dots = Freshwater Natural wetlands (n = 7). Dark green dots = Freshwater Restored wetlands (n =10)

Figure 13:Aerial imagery of the Kohuora park region, showing the locations and geographical layout of the replicates.

Figure 14: Picture of KOHREP 3 plot. Blue pole marks the P location while tape measure line is led to the next corner.

Figure 15: Picture of KOHREP 4, Blue plastic pole marker for P. Shows high levels of raupō, bullrush (Typha orientalis) at observer level.

Figure 16: Dense nearly 2m tall thorny blackberry (Rubus fruticosus). Unfortunately, there was no path around it as it surrounded KOHREP 5 and required slow and painful navigation through the dense bushes.

Figure 17: Picture on the general direction of KOHREP 1, which was inaccessible due to the incredibly dense thorny blackberry and water channels.

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APPENDIX A

Meta data collected for each wetland plot, including the vegetation sampling plot and surrounding wetland vegetation.

Data field	**Explanation**
Wetland hydro-system[1]	Based on broad hydrological and landform setting, and salinity: Options were Estuarine, Geothermal, Inland Saline, Lacustrine, Marine, Nival, Plutonic, Riverine and Palustrine. Note that no geothermal, inland saline, marine or plutonic wetlands were sampled as part of the WMP.
Wetland sub-system[1]	A descriptive level relating to water regime: Options were Ephemeral or Permanent
Wetland class[1]	Based on substrate, water regime, nutrient status and pH: Options were Bog, Ephemeral, Fen, Marsh, Pakihi, Saltmarsh, Seepage, Shallow Water and Swamp.
Wetland form[1]	The dominant landform which creates or contains the wetland: Options were Abandoned River Channel, Basin, Channel, Doomed Bog, Dune Slack, Fan, Flat, Mudflat, Other, Plateau, Pool, Rand, Slope, Spring, String Fen, Swale and Terrace.

1 = Classification of these data fields was done according to the descriptions and keys within Johnson and Gerbeaux (2004)

APPENDIX B

More detailed outline of the Auckland Council's terrestrial biodiversity & wetland monitoring programs

In the 2009/10 field season the former Auckland Regional Council (ARC) commenced the first ever program designed to provide representative, region-wide monitoring of forest (2019) and wetland (2010) biodiversity across the Auckland region; the Terrestrial Biodiversity Monitoring Program (TBMP). Initially TBMP was used to monitor multiple facets of Auckland assets of forests and birds systematically. However, on the 1 November 2010 the ARC was dissolved into the new Auckland Council unitary authority, and the RIMU of Auckland Council took over responsibility for the TBMP.

This transfer of responsibility to the RIMU of Auckland council led to the expansion of the TBMP and the development of the Wetland Monitoring Program (WMP). Furthermore, this led to the development of Regional Council Terrestrial Biodiversity Monitoring Framework (RCTBMF) in 2010, which was designed to act as foundational structure to adhere to requirements for the planning and sustainability of terrestrial biodiversity while meeting regional council standards. This also allows for further identification and focus of the biodiversity outcome of selected monitoring projects and programmes as to help identify the number and types of indicators which can help towards the design and development of future monitoring programmes.

The WMP is based around five-yearly vegetation, bird and wetland condition monitoring of approximately 180 wetlands throughout the Auckland Region, including the Hauraki Gulf islands. The wetlands which receive regular monitoring were selected using a 4km x 4km grid to ensure representative spatial coverage. The scale of these programmes allowed for the measurement of changes within the native biodiversity of the wetlands alongside examining the distribution of weeds and pests. The significance of the data collected by the WMP is vital towards assessing the progression of implemented policies and conservation plans as it allows analyzation of the sustainability and visibility towards if goals are being met. The data accrued is also quite diverse, allowing for wider interpretation in conjunction with other monitoring programmes